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LYTRO: THE CAMERA AS HYPERSENSOR

> You don't take a photograph, you make it.
> (A. Adams)

Abstract

This article examines the Lytro Illum, a 'plenoptic' or 'light-field' camera. This device captures information on the colour, intensity and angle of incidence of each incoming photon and uses that to reconstruct the three-dimensional environment of the scene in the frame. The output file is an image that is quite easy to navigate and refocus. This type of image derives from the hybridization of digital photography, computer vision and computer-generated imaging within the fast-growing broader field of *computational photography*.

This article starts by addressing the Lytro's theoretical and technological bases; more precisely, it highlights the Lytro's place in the wider quest to develop a device that can completely recreate reality in digitalised form. The spotlight then shifts to two aspects of computational photography that are significant for visual theory: its relationship with the interactive effort of the human imagination (following PietroMontani's idea) and its importance in the context of a broader theory of the sensors as basic apparatuses of enunciation.

Keywords

Lytro; light-field camera; plenoptic camera; computational photography; sensor.

1. THE LYTRO ILLUM

The *Lytro Illum* is an innovatively designed digital camera for the *prosumer* market that went on sale in April 2014, priced at around 1,500 dollars. The manufacturer, Lytro, was set up in 2006 by Ren Ng, a researcher at Stanford University Computer Graphics Laboratory.

I have written that the Lytro Illum "appears" to be a camera, because in reality it is different from a normal DSLR (Digital Single-Lens Reflex) camera. Whereas a DSLR composes a given image through a lens on a digital sensor, Lytro's devices also have an array of lenslets (or microlenses) between the main lens and the sensor to break down the individual image on entry into tens of thousands of independent images (200,000 in the Illum's case).The Illum's specially designed CMOS (Complementary Metal Oxide Semiconductor)sensor thus receives, analyses and recomposes a vast number of differ-

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ent images. And it does so in a particular way: using specific software that exploits the technological advances behind CGI (computer-generated imagery) and computer vision, the *Lytro* analyse not only the brightness and colour but also the angle of incidence of each incoming photon. From that, they can calculate the photographed objects' distance and position relative to the lens and thus reconstruct a definitive three-dimensional model of the photographed scene[1]. When the shutter is released, the end product is a very special photographic image: a "raw" file that can be used with dedicated viewing software to obtain a potentially infinite series of photographs with different horizontal and vertical viewpoints (within a necessarily limited spatial range) and to focus the objects inside the field of view. The same file can also be used to generate a 3D image to view using special visors, e.g. VR (virtual-reality) devices[2].

Clearly, then, the Illum is more than just a 'camera'; indeed, its creators term it a 'light-field camera' or 'plenoptic camera'[3] – two definitions to which we shall return shortly. The image produced by the Illum can also be considered part of a new area of photographic images situated at the point where digital photography, CGI and computer vision meet, which is called 'computational photography'[4].

In this article, I shall examine some theoretical implications regarding light-field or plenoptic cameras and the computational-photography images that they produce. I shall do so more in note form rather than as a conclusive discussion, partly because this research field and market are fluid and continually evolving. In section 2, I deal with the processes that have helped to shape the Lytro, spotlighting in particular the utopian projects that have driven this research field. Section 3 focuses on some of the implications of computational images as regards the experience of viewing them: in particular, I shall consider these images in relation to current thinking about 'sensory technologies'. Finally, the concluding section offers some quick observations on the Lytro as a device for 'capturing' the visible scene, with a special emphasis on the key element of this process: the sensor.

2. LIGHT FIELDS AND PLENOPTIC CAMERAS

As I mentioned above, the Lytro's creators categorise it among the photographic devices known as 'light-field cameras' or 'plenoptic cameras'. The two terms are not exactly equivalent. Indeed, they draw on two distinct traditions of research and technological development that are converging and cross-fertilising, thus revealing the approaches

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[1] See also "Light Field Forum. Your News Source for all things Light Field", http://lightfield-forum. com/what-is-the-lightfield. Accessed January 7, 2016. For these reasons, not even the traditional calculation of the sensor resolution in Megapixels applies to the Lytro, which calculates it in Megarays instead, i.e. in millions of analysable photons: "For example, the 40-Megaray Lytro ILLUM is in fact a 40 MP sensor that has a 200,000 microlens array placed on top of it. However, the end resolution won't be a 40 MP image due to the way data is broken down and analyzed". See also "The Science Behind Lytro's Light Field Technology and Megaray Sensors", http://petapixel.com/2015/06/22/the-science-behind-lytros-light-field-technology-and-megaray-sensors. Accessed January 7, 2016.

[2] Readers can explore the possible ways of viewing the images produced with the Lytro Illum on the website https://pictures.lytro.com. Accessed January 7, 2016.

[3] R. Ng et al., "Light Field Photography with a Hand-Held Plenoptic Camera", *Stanford University Computer Science Tech Report*, 2 (2005): 1-11.

[4] R. Lukac, ed., *Computational Photography. Methods and Applications*, Boca Raton-London-New York: CRC Press, 2011. Indeed, computational photography embraces numerous areas, from the 'simple' HDR software already widely used in smartphones to light-field photography and automated facial and object recognition.

and drivers that have guided and continue to guide this field of research and practical applications.

The concept of "light field" was introduced in 1846 by the English physicist Michael Faraday. In a conference entitled *Thoughts on Ray Vibrations*[5], he proposed an interpretation of the propagation of light as the diffusion of vibrations through the air in all directions – analogously to the magnetic field that he had been studying for several years. In 1936, his Russian colleague Alexander Gershun coined the term "light field" in a study of the radiometric properties of light in a three-dimensional space[6]. Gershun shifted the concept from physical to geometrical optics; this perspective laid the ground for the modern concept of light field as a vector function that describes the quantity of light flowing in every direction through each point in space.

After a series of purely photometry-related developments, the early 1990s brought a new shift in the light-field concept. It was taken up by CGI researchers, who were interested in the possibility of simulating the optical and physiological mechanisms of human vision through computer-generated images[7]. In this context, Edward H. Adelson and James R. Bergen spoke of a specific 'plenoptic function', which could measure the radiance of (i.e. the amount of light transported by) every light ray in a three-dimensional space under constant uniform illumination. If an object is introduced into this space, it will obviously cause the rays in the field to be reflected in a certain way, thus making the function more complex.

The introduction of the adjective 'plenoptic' will not have escaped the reader. It refers to the reformulation of the means of measuring the light field as a function of the *light-field rendering*[8]. Indeed, CGI research revives the second tradition of studies that I mentioned, regarding "multi-lens photography". In 1908, Gabriel Lippmann (an inventor working in Germany and France, who won the Nobel Prize for physics that year for his research on colour photography) had conceived an *integral-photography* (*photographie intégrale*) device. It involved laying out an array of microlenses, each linked to a minuscule camera obscura that could form an image on an equally minuscule sensitive area. Such a device could produce a hyper image that, once recomposed as a whole, would make it possible to simulate the normal sensory-motor (and stereoscopic) approach to reality:

> En résumé, la pellicule constituée comme il a été dit plus haut permet de prendre des vues sans chambre noire et montre ensuite les objets photographiés en vraie grandeur et en relief, sans appareil stéréoscopique. De plus, leur aspect change avec la position du spectateur, comme si celui-ci se trouvait en présence de la réalité[9].

[5] M. Faraday, "Thoughts on Ray Vibrations", *Philosophical Magazine*, 28, 188 (1846): 345-350, then in Id., *Experimental Researches in Electricity*, Vol. 3, London: Taylor and Francis, 1855, 447-452, online at www-spof.gsfc.nasa.gov/Education/wfarad1846.html. Accessed January 7, 2016.

[6] A. Gershun, "The Light Field" [1936], *Journal of Mathematics and Physics*, 13 (1939): 51-151.

[7] W. B. Thompson et al., *Visual Perception from a Computer Graphics Perspective*, Boca Raton-London-New York: CRC Press 2011, 193-232. The phenomenological basis of these approaches is illuminated by S.C. Pont, "Spatial and Form-Giving Qualities of Light", in L. Albertazzi, ed., *Handbook of Experimental Phenomenology. Visual Perception of Shape, Space and Appearance*, Malden, Mass.-Oxford: Wiley-Blackwell, 2013, 205-222.

[8] M. Levoy, "Light Fields and Computational Imaging", *IEEE Computer*, 8 (2006): 46-55.

[9] G. Lippmann, "Épreuves réversibles. Photographies integrals", *Comptes Rendus de l'Académie des Sciences*, 146 (1908): 446-451 (449); see also G. Lippmann, "Épreuves réversibles donnant la sensation du relief", *Journal de Physique*, 4e série, t. VII (1908): 54-58.

The meeting between CGI and multi-lens photography is key to our discourse. On the CGI side, indeed, the use of photography constitutes a complete about-turn in the approach to image production. For it is no longer a matter of constructing a *virtual* three-dimensional environment from nothing; rather, it is about reproducing a *real* three-dimensional environment, making it explorable after the 'shot' that reproduces it is taken. In other words, it is a step from CGI to computer vision. The two kinds of approach are not actually opposites at all. Indeed, to construct an environment like that, all the photographs undoubtedly need to combine together based on specific computer-vision processing and recognition mechanisms, while CGI-specific algorithms are also required to reconstruct the space in 3D. That is how the hybrid research sector known as computational photography has taken shape.

Besides, that meeting also has some significant implications as regards multi-lens photography, as CGI and computer-vision researchers are broadening the scope of Lippmann's device. For whereas the Franco-German inventor envisaged that *integral-photography* would simulate the sensory-motor situation of a subject in a real scene during the process of displaying the photograph, the computer graphics researchers aimed to design a hyper-eye that could film a three-dimensional environment from any direction and at any distance while also including the dimension of movement. Lippmann's integral photography turned into the ideal of a genuine *holographic film*:

> A true holographic movie would allow reconstruction of every possible view, at every moment, from every position, at every wavelength, within the bounds of the space-time wavelength region under consideration. The plenoptic function is equivalent to this complete holographic representation of the visual world. Such a complete representation would contain, implicitly, a description of every possible photograph that could be taken of a particular space-time chunk of the world (neglecting the polarization and instantaneous phase of the incoming light) […][10].

In short, the meeting point between computer graphics research and multi-lens photography produces the utopia of a hardware and software device that provides a navigable three-dimensional reproduction of a real environment in motion. That is what the terms 'light-field' or 'plenoptic' photography refer to. To achieve that, the CGI algorithms need to be hybridised with the computer-vision algorithms for processing and combining photographic images; the result is computational (cine)photography. As regards the hardware, devices need to be designed that are not only *multi-lens*, like Lippmann's, but also *multi-camera* (e.g. with many cameras arranged around a given object), *multi-frame* (creating cameras that can capture a 360° view of their surroundings) and *multi-shot* (from a simple photograph to a complete movie).

When formulated, though, the project seems over-ambitious, although it will be (and still is) a powerful driver for theoretical and applied research in the sector. In 1992, Edward Andelson and John Wang sought to revive Lippmann's idea of multi-lens photography, and implemented it using the new digital sensors. It was their idea to introduce an *array of lenslets* between the main lens (known as the *field lens*) and the digital sensor, thus obtaining a new type of camera that they called, not by chance, 'plenoptic'[11]. In

[10] E.H. Adelson, J.R. Bergen, "The Plenoptic Function and the Elements of Early Vision", *Computational Models of Visual Processing,* edited by M. Landy, J.A. Movshon, Cambridge, Mass.: The MIT Press, 1991, 3-20 (5).

[11] E.H. Adelson, J.Y.A. Wang, "Single Lens Stereo with a Plenoptic Camera, *IEEE Transactions On Pattern Analysis And Machine Intelligence*, 14, 2 (1992): 99-106.

2004, the Stanford University research team built a 16-megapixel plenoptic camera with 90,000 microlenses, concentrating their research efforts on refocusing the final image rather than on the three-dimensional effects. The Stanford work led directly to the Lytro applications with which we began[12].

Multi-lens cameras are clearly only a temporary approximation of Adelson and Bergen's holographic-film model. Nevertheless, that model continues to underpin this research field, as demonstrated by Lytro's announcement, on 5 November 2015, of the release in 2016 of a new device: the *Lytro Immerge*. The Immerge's image-capture device comprises a sphere with sensors arranged in five horizontal rings in grooves around its outer surface; they capture a 'light-field volume', i.e. a 360° hyper image of the device's surroundings. The Immerge can also detect and record changes and movements in its field of view[13]. The output of the capture processes consists in a moving VR environment that can be viewed via any device already on the market or under development, from Oculus Rift to Sony PlayStation VR.

3. COMPUTATIONAL PHOTOGRAPHY AND INTERACTIVE IMAGINATION

At first sight, computational-photography images, such as those obtained using a Lytro Illum, have all the characteristics of digital images. In particular, the digitally constructed image is aptly characterised not as a stable object for disembodied viewing but rather as a framework of processing that requires an overt bodily intervention by the viewer. For example, Mark Hansen has observed, "Digitization requires us to reconceive the correlation between the user's body and the image in a […] profound manner [… Indeed], the 'image' has itself become a process and, as such, has become irreducibly bound up with the activity of the body"[14].

In another context (more Merleau-Pontyan than Bergsonian), Roberto Diodato has considered the idea of the "virtual body" as a "structurally relational environment" characterised equally by its virtual and relational dimensions and thus resistant to categorisation in terms of either the internal-external or the object-event dichotomies[15]. It is a body-environment that, like Foucault's image of the dream for Binswanger, "is not a modality of the imagination. It is the fundamental condition for it to exist"[16]. The computational-photography image is clearly a type of virtual body-environment of this order.

On closer inspection, however, computational-photography images reveal a specific, irreducible character compared to pure digitally produced images. In this case, indeed, the virtual matrix of the observer's acts of viewing, focusing and shifting position does not derive from a new construction out of nothing using computer graphics. On the

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[12] The Lytro project is not the only one in the light-field camera sector: for example, Adobe has developed a 100-megapixel prototype using 19 lenses equipped with internal microlenses. In this sense, the plenoptic light-field camera with flat array differs from the 'autostereoscopic' version, which uses a circular array to enable 3D effects – although something similar can be achieved by reproducing the effect of binocular vision.

[13] T. Moynihan, "Lytro Immerge: Groundbreaking Camera Will Let You Move Around in VR Video, *Wired*, November 5, 2015, www.wired.com/2015/11/lytro-refocuses-to-create-a-groundbreaking-vr-camera. Accessed January 7, 2016. As the project founders, Paul Raphael and Félix Lajeunesse, sum up in the product presentation video (viewable at www.lytro.com), "We're trying to replicate reality, here".

[14] M.B.N. Hansen, *New Philosophy for New Media*, Cambridge, Mass.: The MIT Press, 2004, 10.

[15] R. Diodato, *L'invisibile visibile. Itinerari di ontologia estetica*, Milano: Mimesis, 2012, 29-55; see also Id., *Estetica del virtuale*, Milano: Bruno Mondadori, 2005.

[16] M. Foucault, "Introduzione", in L. Binswanger, *Sogno ed esistenza* [1930], Milano: SE, 1993: 73, cit. in Diodato, *L'invisibile visibile*, 52.

contrary, it is a matrix comprising multiple *indicial images*, characterised by that "has been" that, as is known, constitutes the *noema* of the photograph and its *arché*[17]. This aspect, in my view, introduces an essential difference between the synthetic image (characteristic, among other things, of VR) and the computational-photography one[18]. I shall attempt to bring out this particular aspect through a dialogue with the recent current of thought started by Pietro Montani on the relationship between sensory technologies and the interactive work of the imagination.

In his latest book, Montani reflects on the relationship between imagination and technological devices within an aesthetic viewed as "a critical reflection on human sensory capabilities and qualities"[19]. In this context (and through a Kantian and Garronian process that I cannot reconstruct here), he emphasises in particular the *interactive* (and thus technically oriented) aspect of the imagination. He considers its function to be that of interfacing sensation, perception and language within an *experimental* exploration of the real. On one hand, he says, this process exhibits a pragmatic, sensory-motor dynamic (in a form that seems to me to derive from the hypothesis of an 'embodied simulation' of pragmatic, haptic and prensive means of perception, including in the purely visual forms of exploration[20]). On the other, the process cross-references sensory and linguistic data to produce interpretative hypotheses, including those of a pragmatic and technological nature. For example, given an oleander branch and a willow branch, the subject will identify both 'salient' features (their different levels of flexibility) and 'emerging' [*sopravvenienti*] – for instance, that only the oleander branch can withstand a process of accumulating and releasing force and can thus be used as an archery bow[21].

If we compare Montani's analyses with the experience of viewing computational photographs, then we can make two observations. First, the computational-photography images enable us to make movements[22], to represent them as we please in especially evident ways, and to do likewise with the exploratory experimental actions that are native to the interactive imagination. If, for instance, we had the image of an oleander branch and a willow branch shot using the Lytro Immersive, then we could visually weigh up how solid they are from different viewpoints and different distances, moving back and forward and focusing on one or the other in turn, as we wished and as often

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[17] The references are obviously to R. Barthes, *Camera lucida* [1980], New York: Hill and Wang, 1981, and to J.-M. Schaeffer, *L'image precaire. Du dispositif photographique*, Paris: Éditions du Seuil, 1987. On the problematic nature of an overlap between indicial and analogue (and thus between virtual and digital), see, among others, D.N. Rodowick, *The Virtual Life of Film*, Cambridge, Mass.-London: Harvard University Press, 2007.

[18] The same term 'Virtual Reality' effectively seems inadequate for interactive environments constructed via computational photography: a tempting alternative might be 'mixed reality', had this not already been used in a precise theoretical context to mean the continuity with which the subject's body moves from real to digitally generated three-dimensional environments: see M.B.N. Hansen, *Bodies in Code. Interfaces with Digital Media*, New York-London: Routledge, 2006. In the case of computational-photography images, perhaps we can dare to use the term 're-mixed reality'.

[19] P. Montani, *Tecnologie della sensibilità. Estetica e immaginazione interattiva*, Milano: Raffaello Cortina, 2014, 29.

[20] On these aspects, with particular reference to the cinema experience, see V. Gallese, M. Guerra, *Lo schermo empatico. Cinema e neuroscienze*, Milano: Raffaello Cortina, 2015.

[21] Montani, *Tecnologie della sensibilità*, 21-38.

[22] I refer to 'movement' in terms of simulation, at different levels: the shift permitted by the computational-photography viewing devices may be merely simulated mentally, produced virtually using the mouse or other kind of tool, or (with the Lytro Immerge, as mentioned) produced virtually but with the involvement of our actual locomotive systems by moving our faces or entire bodies monitored by suitably placed sensors.

as we wanted. Note, however, that in this case, we are not experiencing and observing the transcendental conditions of the workings of our imagination, as if the two branches were a more or less accurate computer-generated image viewed using a normal VR system. Rather, we are *actually acting out,* albeit in reflexive form, the workings of our interactive imagination. This point therefore brings out the first key peculiarity of computational photography compared to digital images in general.

The second observation shifts attention from the spatial to the temporal level. While we explore it by 'moving' in various ways, the computational-photography image remains fixed, frozen in the moment when it was captured. The situation evokes those videos or film sequences in which the camera's viewpoint moves around in a frozen three-dimensional world – as in the video *Carousel* (Adam Berg, 1999), produced by Philips as a commercial using almost exclusively live footage[23]. In both cases, the image deploys *two different, non-communicating temporalities*: that of the represented world (reduced here to a single instant) and that of the sensory-motor act of exploring that world. The latter follows the rigidly predetermined unfolding of the film image in the case of *Carousel* and similar videos while maintaining the elasticity and indeterminate nature of the casual action in our interactive exploration of the computational-photography image. Thus emerges a second distinctive trait of computational photography compared to the digital image constructed by the computer. That is, whereas VR environments can interact with their user (for example, generating transformations in real time, as in a videogame), computational-photography images inhabit an unbreakable time capsule. In other words, they confine the user to a temporality that is irreducibly different from that of the represented scene.

In essence, then, the devices for consuming computational-photography images constitute specific forms of delegating sensory perception to a technical proxy (to cite Montani's concepts again). Given that they arise from the hybridisation of ultra-high-definition photographic images with VR environments, they enable the interactive imagination's own processes of exploring and experimenting to play out in a clear, open and repeatable form. Yet (and in a closely connected way) these processes' temporality is separated from that of the observed world. Computational photography thus gives us access to 'real' worlds – in the sense that they have "really" been in front of the lens(es) – although they do not belong to us (at all or any more), and above all we do not belong to them either (at all or any more). The evident and effective operation of my sensory-motor exploration of a world is compensated for and made possible by performing those activities within a temporality that is independent from that of the perceived scene – and hence infinitely extendable and observable.

4. TOWARDS A THEORY OF THE SENSOR

In the previous section, I discussed various grounds for theoretical interest in the practices and experiences of viewing computational-photography images. In this concluding section, I look at the theoretical implications of the devices that produce this kind of image, focusing in particular on the key element in the process: the *sensor*.

I shall briefly outline the reason for the interest in thinking about the sensor today.

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[23] See the analysis of the video by P. Hesselberth, *Cinematic Chronotopes. Here, Now, Me*, New York-London: Bloombsury, 2013, 1-3.

A 'post-media condition' is now taking shape, as Rosalind Krauss and Felix Guattari respectively describe[24]. This development has been prompted by a series of well-known phenomena: the individual media's loss of specificity; some media's loss of importance in the overall media universe; and a blurring of the borders between media and non-media contexts. Given such phenomena, in my view it is not enough to attempt to adapt models and concepts developed for the previous media condition to the new context; I refer, for example, to worlds and conditions that are *post-cinematographic*, *post-cinematic* and *post-televisual*. Rather, a research strategy needs to be devised that focuses on some elementary objects that cover but go well beyond the arena of media and representation. One such is the *sensor*. It is special, if nothing else for its omnipresence and its vital role in countless processes – from sensors in the places we frequent and in the objects we use to those we wear and even those that can be implanted in our bodies[25].

In general, a sensor is a device that receives and responds to a signal or stimulus. In a narrower technical sense, though, "a sensor is a device that receives a stimulus and responds with an electrical signal", be it electrochemical (as with biological sensors) or electronic (as with artificial sensors)[26]. Based on these properties, sensors can act as an interface between the world and digital systems, in that electrical signals can be encoded in bytes. For example, the CCD (Charge Coupled Device) sensor in a camera encodes the image projected by the lens onto its surface into electrical impulses that are then translated into binary strings by an Analogue/Digital converter, whereas in CMOS sensors, the conversion takes place inside the sensor itself. Note that, through a synecdoche, the term "sensor" even covers the processing of digitally produced images using software *after* the A/D encoding. Consider, for instance, the various forms of object recognition (as used for product quality control in industry) or facial recognition (e.g. in the algorithms in surveillance software or, more mundanely, in our smartphone cameras).

A sensor is a special kind of *transducer*, a device that converts one form of energy into another (more or less proportionately).The opposite type of transducer is the *actuator*, which turns electrical impulses into mechanical or other forms of energy, such as the digital camera's LCD (Liquid Crystal Display), which converts the electrical impulses emitted by the sensor into photons using the polarising properties of liquid crystals. As the camera example clearly demonstrates, sensors are incorporated into complex systems with other components, especially transducers and actuators:

> In summary, there are two types of sensors; direct and complex. A direct sensor converts a stimulus into an electrical signal or modifies an electrical signal by using an appropriate physical effect, whereas a complex sensor in addition needs one or more transducers of energy before a direct sensor can be employed to generate an electrical output[27].

[24] R. Krauss, *'A voyage on the North Sea': Art in the Age of the Post-Medium Condition*, London: Thames & Hudson, 1999; F. Guattari, "Vers une ère post-média" [1990], *Chimères*, 28 (1996): 5-6; F. Casetti, "I media nella condizione postmediale", in *Estetica dei media e della comunicazione*, edited by R. Diodato, A. Somaini, Bologna: Il Mulino, 2011: 327-346; A. Pethö, ed., *Film in the Post Media Age*, Newcastle upon Tyne: Cambridge Scholar, 2012; C. Appritch et al., eds., *Provocative Alloys: a Post-Media Anthology*, Lünenburg: Post-Media Lab & Mute Books, 2013; R. Eugeni, *La condizione postmediale*, Brescia: La Scuola, 2015.
[25] For a survey of recent technology research, see, for example W. Barfield, *Cyber-humans. Our Future with Machines*, Heidelberg-New York: Springer, 2015, 177-214.
[26] J. Fraden, *Handbook of Modern Sensors. Physics, Designs, and Application*, Heidelberg-New York: Springer, 2010[4], 15.
[27] *Ibid.*, 18.

There are many reasons for a theoretical interest in sensors. First (as mentioned earlier), sensors are originally made not in the world of media and representation but in industry for safety, measurement and similar purposes. Although they still exist in such settings[28], they have also spread across the media arena, as an emblem of the constant contemporary exchange of technologies, experiences and forms between media and non-media contexts. The second reason for this interest is the possibility of connecting and hybridising biological and physiological sensors (like the electrochemical type mentioned earlier) with electronic sensors. Indeed, many medical and prosthetic devices, from *pacemakers* to new artificial organs, systematically adopt this type of hybridisation. Finally, the third reason is more strictly semiotic, concerning the possibility of considering sensors as *basic apparatuses of enunciation*.

In this light, I would like to propose a fundamental distinction between three types of sensor: *agency sensors* (which combine with actuators to initiate a physical process, such as the infrared movement detectors that automatically trigger the camera when a subject passes in front of it); *display sensors* (which are linked to a display to produce an image, as with a camera display); and *track sensors* (which create a track when connected to a memory device: the typical case is the camera's *raw* file, which has not yet been digitally processed).

These considerations bring us back to the Lytro Illum and the problems of the plenoptic camera. The Lytro sensor is a *hypersensor*: a high-density CMOS sensor built for use with the plenoptic camera's dual system of lenses (single lens + array of lenslets) to gather a huge amount of data about the visible scene. Nevertheless, there is an essential difference compared to the sensors in traditional digital cameras: whereas the latter can immediately create an image on the camera's display, the amount of data collected by Lytro's shot cannot be fully visualized. Thus, although at first sight it may appear to be a *display* sensor, the Lytro sensor actually proves to be a pure *track* sensor, intended to produce a matrix of information that only other devices can subsequently and partially display.

(*Translated by Oliver Lawrence*)

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[28] S. Soloman, *Sensors Handbook*, New York-Chicago: McGraw-Hill, 2010[2], in particular XXV.