# The Light-Field Stereoscope: Wearable Contact Lenses Capturing 3D Scenes based on Eye Movement Detection

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**Abstract:** ***Inspired by 'The Google Glass', this paper shows a method of capturing 3D images/videos by using a wearable contact lens based on eye movement detection. The paper puts light on the methods that can be used to track and detect eye movement (i.e. blinks or winks) through sensors installed on the contacts for capturing picturesque 3D scenes. The presented paper embeds Light-Field technology in the lens's hardware for enabling enhanced photographic imaging of various scenes. The images captured by the wearable contact lens are wirelessly shared with the nearby user device like cell phone, tablet, desktop, etc. through an antenna, as the entire unit of the lens & smartphone, etc. forms a network of IoT (Internet of Things) devices. These captured images are further processed to give a 3D effect to the static set of photos/scenes.***

**Keywords:** Light-Field, Wearable Contact Lens, Microscopic Lenslets, Sensors.

## 1. Introduction

The paper introduces Light-Field rendering contact lenses capable of controlling an image capturing unit provided in the contact lens. Wearable contact lens include: a lens apparatus configured to be worn on an eyeball, an image capturing unit configured to capture an image of an object based on the eye movement.

Unlike recently patented contact lenses, a Light-Field contact lens allows light to be captured from multiple vantage points, left to right, top to bottom, and all points in-between – with the help of microscopic lenslets (or microlenses) that form the top layer of a lens. The Light Field, with the rays‟ color, intensity and angular directions are captured to produce images with both color and depth, which can be calculated through the intersection of rays of light in the scene.

## 2. Background

Although electronic devices are shrinking all the time, the idea of a smart contact lens still seems wildly ambitious. A patent filing by the Japanese company reveals its vision for a contact lens that not only records video and images with a simple blink, but manages to store them right there and then on the user's eyeballs.

Sony's patent application reveals a smarter, and probably scarier, piece of eyewear. Among the hardware built into the lens would be an image capture unit, a main control unit, storage module, antenna and a piezoelectric sensor.

These piezoelectric sensors would sense how long eyelids remain closed to discern between conscious blinks and unconscious blinks. This would give users a simple control mechanism to capture photos and videos.

As per the patent filing: "It is known that a time period of usual blinking is generally 0.2 seconds to 0.4 seconds, and therefore it can be said that, in the case where the time period of blinking exceeds 0.5 seconds, the blinking is conscious blinking that is different from usual blinking (unconscious blinking)" [1]

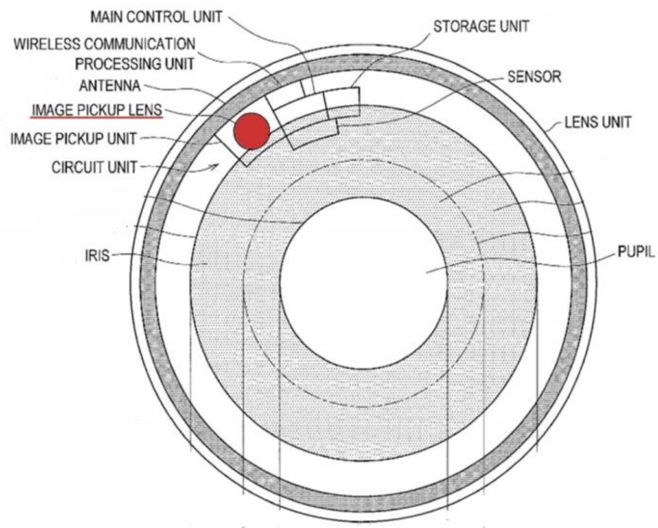


**Figure:** Among the hardware built into the lens would be an image capture unit, a main control unit, storage module, antenna and a piezoelectric sensor [1]

## 3. Light-Field

The LightField is defined as all the lightrays at every point in space travelling in every direction. It is essentially 4D data, because every point in three-dimensional space is also attributed a direction (i.e. the fourth dimension).

As we look at an apple, rays of light are hitting its surface from every direction. They bounce off the skin, the leaves, and the stem, but we only see those rays that reflect towards our eyes and enter through our pupils. We see the apple from two vantage points, our left and right eyes. The side-by-side offset of our eyes gives us a stereoscopic view of the apple, which our brain can use to perceive how near or far the apple is. [5]

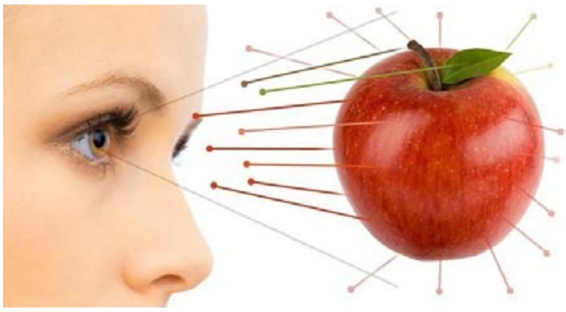

**Figure:** We only see those rays from the light field that reflect toward our eyes and enter through our pupils [5]

A traditional contact lens perceives the apple the same way one of our eyes works. Light rays pass through the contact lens and then hit the sensor or film to form the image it captures. The lens only captures the light‟s color and intensity, but angular information for the corresponding rays isn‟t recorded by the lens. Therefore, conventional contact lenses only record a two-dimensional representation of a scene, using the two available dimensions (length and width; pixels along the x and y axis) of the film/sensor.

## 4. Concept

### 4.1 Hardware

The primary hardware for the eyewear consists of top lens layer containing multiple microlenses for depth capturing of a scene. The bottom lens layer holds the photo/imaging sensors which sense the eye movement to recognize the objects/scenes to be focused on, click photos, or start a video session. These sensors further record the receipt of photons from the objects being zeroed-in on. This gives wearers a simple controllable mechanism for capturing photos and recording videos based on elementary eye gestures.

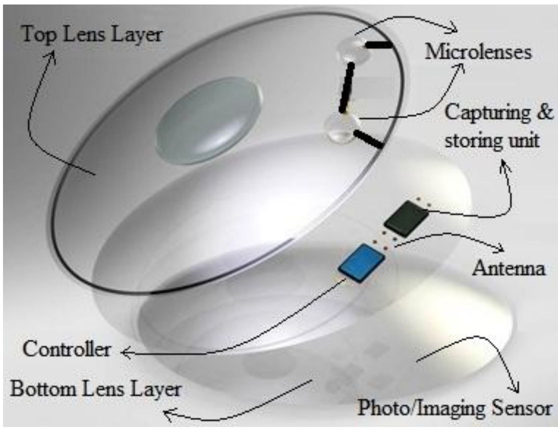


**Figure:** Hardware built into the lens includes top lens layer with microlenses, an antenna, a contoller, a capturing & storing unit, and bottom lens layer with photo/imaging sensor (Source: Google Smart Contact lenses - reformed)

[Note: In the above diagram, only two microlenses are shown as an example to visualize smaller picture of the hardware. In the final product multiple such microlenses would be fixed on the top lens layer of the contacts].

The controller unit controls operation of seizing images/scenes. For example, the control unit performs ON/OFF control operation of the capturing & storing unit. The controller also manages the execution of operations such as autofocus, automatic exposure adjustment, aperture stop adjustment, and zooming for various lenslets based on the extent of eye movement (e.g. winks, blinks) or activity.

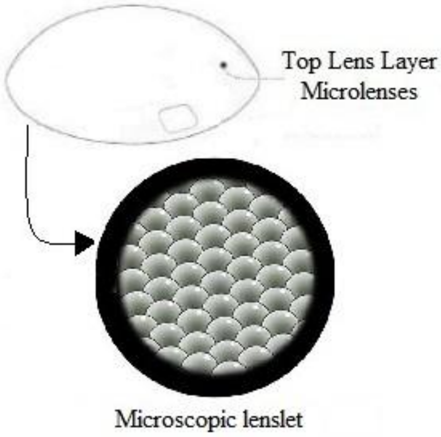


**Figure:** The enlarged image of multiple microscopic lenslets (microlens array) placed above the sensor to capture the Light-Field

The antenna is wirelessly connected to an external device and has a function of transmitting and receiving data. It also serves the purpose of fueling the lens by supplying and receiving electric power. The external device is, for example, a smartphone, a tablet, a personal computer (PC), etc. which exists in the vicinity of the contact lens. Supply and reception of electric power can be achieved by, an electromagnetic induction method, a radio wave method, or an electromagnetic field resonance method [1].

### 4.2 Flowchart

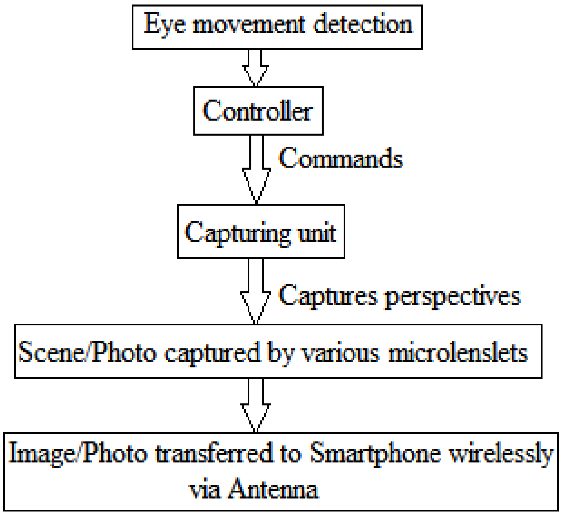


**Figure:** Procedural workflow block diagram [3]

### 4.3 Operation

The proposed concept deals with the modification of lens‟s hardware to implement Light Field technologies, which enable capturing the Light Field, compute the ray angles and then replicate that light field in a virtual space.

Contrary to traditional lenses, LightField contact lenses have a microlens array just in front of the imaging sensor. Such arrays contain multiple microscopic lenslets (in the range of 100,000, etc.) with scaled-down focal lengths, and split up 2D-pixels into individual light rays just before reaching the sensor. The resultant raw image is a blend of as many tiny images as there are microlenslets. The two contact lenses and sensors on either of the eye capture a pair of side-by-side stereoscopic pictures or video of the scene based on eye blink or wink detecting phenomenon. These are technically termed as 3D images, however they are actually a pair of flat 2D images or video that are synched together, offset left to right, which trick the eye (and brain), thus appearing 3D when viewed through an appropriate device.

Interior to the contact lens, light rays with their color, intensity and angular orientation pass through the various layers of the lens. Above the imaging/photo sensor, an array of microlenses foregathers the light rays into tiny image discs. Each disc covers a small portion of the sensor, and the smallest detectable "bundles of rays" correspond to individual pixels on the sensor. The computational engine within the contact lenses processes these bundles of rays, as seen by each pixel on the sensor, and uses a geometric model to calculate the flow of light through a virtual lens. Based on that model and the angular data for each bundle of light, images of different focal points, perspective shifts (i.e. of lenslets) can be generated. Furthermore, focal plane effects can also be simulated to effectuate and amplify 3D pay-off.

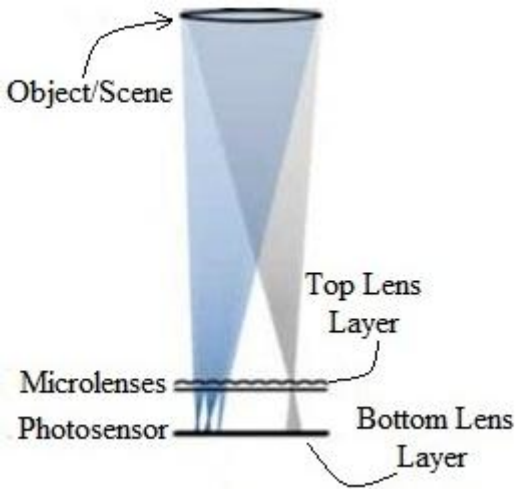


**Figure:** Cross-sectional view of a lens‟s hardware – Top & Bottom Lens Layers [2]

## 5. Image Processing

Upon capturing/recording the tiny images by the sensors, it is observed that every sub-image differs by a slight amount from its neighbors, as the lightrays were deflected slightly inconsistently depending upon the respective microlens‟s position in the array.

Now, an image processing algorithm (or software) is used to find matching light rays across all these images. The software collects the following data: (1) matching light rays, (2) their locale in the microlens array and (3) light rays within the specific sub-images. This information can be used to reconstruct a sharp 3D model of the scene. The mentioned software can be installed on user devices like smartphones, tablets, desktop, etc. for processing the wirelessly acquired images from the contacts.

Using the above model, all of the LightField capabilities are availed at one‟s fingertips: one can define what parts of the image should be in focus or out of focus, define the intensity/depth of field, one can set everything in focus, one can shift the perspective or parallax a bit. One can even use the parallax data to create 3D pictures from a LightField capturing lens. All of this can be done after recording and storing the images on the lens.

**Figure:** Different sections of an image seen in-focus in two adjacent pictures by a simple shift in perspective (Source: www.lytro.com)

**Figure:** Light-Field technique aids to focus on various parts of an image as per choice that leverages enhanced photographic quality of a scene/photo [4]

## 6. Conclusion

Thus, in Light-Field capturing system each lenslet in the contacts, captures the scene from a slightly different perspective and contributes to varied vantage points. Every vantage point in the array is then merged to produce Light-Field images. For producing effective 3D masterpieces, every lenslet in the array needs to be perfectly synched, with carefully measured orientation, focal length, shutter timing (of various lenslets), and exposure which is controlled by the eye movement of the user.

## 7. Acknowledgement

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## References

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