Dye sensitized photovoltaic miniaturized solar cells, used as optical sensors for line of sight detection

Cortes Torres Carlos Cesar\textsuperscript{1,2}, Kota Sampei\textsuperscript{2}, Ogawa Miho\textsuperscript{2}, Ozawa Masataka\textsuperscript{2}, Miki Norihisa\textsuperscript{2,3}

Keio University 3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8522, Japan
cortestc@a6.keio.jp

Abstract. Dye sensitized photovoltaic devices have been studied as transparent and low-cost solar cells. Our group have miniaturized the cells and used them as transparent optical sensors. This paper reports the design and fabrication of the cells and avoids the cross talk among cells, which was found recently and such effect provokes hardware instability.

We use these optical sensors as an eye tracking device. The sensor array detects the difference in the intensity of light reflected from the pupil and the sclera and then determines the pupil position. Each sensor consists of two electrodes and electrolyte; hence our device conformed by only four semi-circular shaped sensors on eyeglasses can detect the view angle in both horizontal and vertical directions. Manufacturing process gives us freedom to easily re-arrange, add or remove sensors.

In our prior work we had good performance in stand-alone configuration. We used specialized equipment from National Instruments for our measurements. However we found that:

A cell is not 100\% independent from the others, is affected by the absence or presence of light at the neighbour cells. When our device is connected to other electronic devices (for data processing), all cells have the same voltage among them; therefore, all cells behave the same way when any of them is affected by light.

The root cause is, due to all sensors were interconnected via a micro channel and filled with electrolyte, due to its conductive properties, electrolyte does neither need electrodes nor physical paths to conduct electricity, so it creates a liquid wire between sensors, hence the gap between them become inexistennt, consequently when our device is connected to other electronic devices, due to this unique channel and by sharing a common electronic ground, this connection provokes the voltage to be the same among all sensors in the array. Our device becomes four separate voltage lines in a parallel circuit.

The device was also in short circuit provoked by some overlapping paths, despite that such paths were in different layers and separated by an adhesive film of 100μm thickness, such thickness was not large enough to creates a successful dielectric to isolate the paths.

\textsuperscript{1} To whom any correspondence should be addressed
\textsuperscript{2} Keio University 3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8522, Japan
\textsuperscript{3} JST PRESTO 7, Gobancho, Chiyodaku, Tokyo, 102-0076, Japan
Our proposal is to encapsulate electrodes individually and apply printed circuit board routing rules. This improves each sensor independency without compromising the performance of the other sensors and a more reliable circuitry, stable voltage and higher accuracy can be achieved.

Results: Electrical tests revealed improvements in voltage response. The best case for voltage dropped in prior work was a 30.5%, while in the proposed design is 11.15%.

1. Introduction

Our device is compound by 4 sensors; each sensor is compound by 2 electrodes and is interconnected by a channel filled with electrolyte which will transport the charge, the sensors react to the light and convert it into DC voltage. Our line of sight device works in the principle that based on the difference in the intensity of light reflected from the pupil and the sclera to detect pupil position.

We use dye sensitized photovoltaic technology and miniaturizing solar cells by applying patterning process of photoresist and etching process, we use them as optical sensors. Figure 1 illustrates our device.

![Figure 1.](image)

Figure 1. (A) Our wearable eye tracking device. The subject Line-of-sight (LOS) can be deduced from the sensor outputs. (B) The output of the sensor. Reflected light from the pupil is smaller than the sclera (white of the pupil.) The difference of the output is calculated to the view angle.

Because of this channel that interconnects all the 4 pairs of electrodes, thanks to the electrolyte, the charge is transported through the redox couple and this converts the device from 4 sensor array (intended design) to a single sensor (real design). Figure 2 describes the fabrication processes.

![Figure 2.](image)

Figure 2. Fabrication and assembling process

When design electronic devices there are few things that should be consider, like: precision, fiability, robustness, etc. Also, an important point to highlight is that as the device size decreases (miniaturization) the risk of issues increases, in the case of our research we had the issue that sensors and transmission lines interference with each other (cross talk), so the a cell is not 100% independent from the others, is affected by the performance of the neighbor cells.
2. Hardware design

Several experiments were conducted, like: usage model experiments (gazed a point by some amount of time and then gazed another point, etc. trying different sequences for each experiment). However when testing the behavior of sensors individually, an experiment showed that an X sensor alters its normal performance even if the light conditions remains the same in that sensor, but it does change respect with Y sensor. The hardware set up for these experiments is: lab view software, national instrument acquisition card NI 9215 and control module NI cDAQ-9178 and multimeter.

A second hardware set up was used to verify the device performance. The hardware set up for this experiment is: line of sight device coupled to an android phone through IOIO-OTG board, external circuitry and multimeter. This showed that when our device is connected to other electronic devices (for data processing), all cells have the same voltage among them; therefore, all cells behave the same way when any of them is affected by light.

To narrow down the issue we disassembled the circuit into 3 cross talk current scenarios. In the first stage of this research, we proposed a “prove of concept” design, in which we tested 3 pairs of sensors; each pair modeled a cross talk scenario.

1.- The first scenario tests the interaction of the tracks overlapping with the electrolyte channel between sensors.
2.- The second scenario tests the interaction of the tracks overlapping each other in parallel way, but separated from the electrolyte channel.
3.- The third scenario tests the interaction of the tracks by crossing between them.

These scenarios are explained in figure 3.

![Figure 3. Cross talk basic scenarios. The color of the tracks (blue and black) only indicates that are placed at different layers in the device.](image)

3. Testing

The two experiments consisted in measure the voltage in each pair of sensors one at a time, and then covering one of them and measure the opposite cell, this shows a variation of the output voltage. This experiment was executed in each cross talk scenario described above and for each hardware set up.

In the second stage of this research, a new line of sight design was proposed, we redefine the layout of the circuit diagram and sensors, such sensors are encapsulated individually to provide more performance independency and any crossing tracks or overlapping is avoided. The experiment conducted for this second stage, was additionally to the basic voltage measurement was performed the usage model experiment, in which a user gazed marks in a whiteboard each 5 seconds and we measure the response.

4. Results

The new design showed that the percentage of dropping voltage is minor than the previous design, the
voltage behavior is more steady, Figure 4 shows the voltage response in both cases. In our prior work, the amount of voltage dropped is larger than in our current work. i.e. In prior devices a cell will reduce its voltage by 0.1V, in our current device is only 0.02V (best case), this represents a reduction from 30.5% VS 11.15%.

![Figure 4. Voltage response. A test was conducted in which we cover all cells but one and one at a time, measuring the voltage of the uncovered cell at each step. Vertical lines, red and green respectively (standard deviation), shows the range of voltage that could be dropped in that particular point, down at vertical direction.](image)

5. Conclusions
This research shows that due to the electrolyte conductive properties creates a channel that transports the charge from point A to point B and does not need electrodes or physical paths to transport the charge, so it creates a liquid wire between any points, hence sensors should be encapsulated individually to assure its independency. Also if the electrolyte combined with the physical tracks, empower them, so any cross or overlapping provoke another electric interference despite that such paths are in different layers and separated by an adhesive film of 100μm thickness. Figure 3 illustrates this cross talk issue and illustrates our current proposal.
The other findings was the difference in the results using different hardware set ups, this is due to, by using national instrument equipment, the acquisition cards have more specialized filters to isolate noise and make more precise measurements, the mobile set up was done with multipurpose board and circuits, this set up emulate the output as parallel connection, between all 4 sensors, instead of 4 individual lanes, that’s why all of the sensors in the mobile experiments have the same voltage, and have the same response to light conditions. Thus by removing the cross talk, and let the sensors operates independently, a higher accuracy is achieve.

**References**

[1] Masatake Ozawa, Kota Sampei, Carlos Cortes, Miho Ogawa, Akira Oikawa, Norihisa Miki Wearable line-of-sight detection system using micro-fabricated transparent optical sensors on eyeglasses Sensors and Actuators A 205 (2014) 208–214