An Electro-Oculography Circuit for Detecting Eye Movements for Low-Power Displays

Wei-Chung Cheng
waynecheng@mail.nctu.edu.tw
Department of Photonics - National Chiao Tung University – Taiwan
http://color.di.nctu.edu.tw

Abstract
This demo presents a novel paradigm for power-managing a display based on the user’s eye movement. The display power is reduced by dimming the brightness when the user is not attending to the display content, which is determined by sensing the user’s eye movements with the electro-oculography technique (EOG). An EOG circuit was designed to pick up the electrical signals generated from eye movements, especially the saccades. By analyzing the frequency and amplitude of saccadic eye movements, the user’s viewing status can be estimated and classified into four modes: text reading, image viewing, idling, and away. Different brightness profiles are assigned to different modes by implementing the policy and backlight control within an FPGA board. A custom-made TFT-LCD was used to demonstrate the proposed concept. Up to 30% of power savings can be obtained in our experiments.

1. Introduction
The power consumption of emissive and transmissive displays is correlated with the brightness level. For emissive displays such as organic/inorganic LED, CRT, and plasma, which are self-light-emitting, the brightness is directly proportional to the power consumption. For transmissive displays such as LCD, LCoS, and projector, in which the brightness is controlled by the backlight intensity and the transmission rate of light valves, the power consumption is dominated by the backlight intensity. In both cases, the light source consumes more than 70% of the display power [1].

Previous studies have shown that the display consists of a major portion of energy budget in portable electronic devices [2]. Thus, efficient power management is crucial for low-power displays or systems.

For systems without a display, the proposed technique of sensing the user’s viewing status can also help the power manager make the optimal decisions. For example, an MP3 player can lower its quality of service when the user is concentrating on a text editing task.

To reduce display power consumption, different methods of managing brightness have been proposed. In literature, most works deal with the balance of image quality and power consumption, or, how to reduce the brightness to the minimum power consumption while maintaining the same visual quality. To evaluate visual quality, most efforts had been made to the perceived image quality by the human visual system. In such studies, the user was always assumed to be fully attending to the display content [3-6].

In real world, the users do not always pay full attention to their display. Nowadays most computers and displays are managed by simple time-out policies with decent efficacy.

Time-out can be considered as a very simple form of detecting the user’s inattention by measuring the latency of user’s input activities. To be more aggressive, one can detect the user’s activities by monitoring the user’s actions with a camera [7].

In this work, we propose a new approach to estimating the user’s visual attention. Visual attention is closely related to the gaze position – where the user looks at. The focus of visual attention and gaze position, however, are not always the same.

To collect precise gaze position is not a simple task, which usually requires an expensive and bulky eye-tracker and only off-line statistical data can be offered. Nevertheless, to detect precise gaze position may be difficult, but to detect eye movement may be not. The human eye moves in several common patterns: blink, fixation, smooth pursuit, and saccade. The blinking eye movement lubricates the cornea and cuts off visual information periodically. The fixational eye movement happens when one steadily looks (with involuntary micro-saccades) at a fixed point. Smooth pursuit happens when the gaze position is following a moving target closely, for instance, when one is trying to catch a flying frisbee in the air. The saccadic eye movement happens when the gaze position moves instantly from point A to point B at ultra high speed. For example, when one is comparing two documents side-by-side and moving her gaze position back and forth.

Electro-oculography (EOG) is a technique for detecting eye movements by measuring the resting potential of the retina. When the eyeball rotates, the angular change of retinal potential can be measured from the skin around the eye. To do so, a pair of electrodes is placed to the left and right of the eyes, and an indifferent electrode is placed on the wrist. By measuring changes of the potential difference caused by rotation of the eyeballs, the eye movements can be detected (Figure 1).

Figure 1: EOG configuration.
Based on the saccade frequency and amplitude, we can determine the user’s viewing status as in the text reading, image viewing, idling, or away mode.

The brightness dimming policy is decided by the viewing mode. In the image viewing mode, the brightness is kept at 100% to preserve the image quality. In this mode, the user makes long saccades randomly. In the text reading mode, the user makes short, parallel, and periodic saccades. The user’s gaze position is within neighboring areas with similar brightness. Because of light/dark adaptation (the human visual system adapts to luminances changes), the brightness is dimmed to 75%. Reduced brightness also helps reading comfort. In the idling mode, the brightness is reduced to 0%. In the away mode, the display is turned off to save power.

2. Design of EOG Circuit

The electrical potential level of EOG is very low (50~350μV) so it has to be carefully amplified and filtered to reject the ambient noises including the electromagnetic radiation noise from the 60Hz power line, the electrical signals generated by muscle activities and other organs. Our EOG circuit includes instrument amplifiers (AD620, Analog Devices), a 10Hz low-pass filter, a 2Hz high-pass filter, a twin-T band-rejection (notch) filter, and gain amplifiers (TI OPA 4137) (Figure 2). ORCAD was used to design by schematics. PSpice was used for circuit simulation.

Figure 3 shows the EOG circuit at work. When the eye moves to the right, the right electrode picks up a negative potential signal while the left electrode picks up a positive potential signal. As a result, the potential difference between two electrodes indicates changes of the eye position. The EOG circuit uses +5V/-5V DC power sources and consumes 120mW.

3. Results

Based on [3], the display power $P$ is a quadratic function of normalized luminance $b$:

$$P = 0.0374b^2 + 3.2194b - 10.5760 \text{ (mW)}$$

According to CIELab, the lightness (perceived brightness) is $L' = 116b^{1/3} - 16$. When the lightness level is reduced from 100% to 75%, the luminance can be lowered from 64 to 27 nits, and the power can be cut to 103/350=30%. If a user profile consists of 65% of image viewing, 20% of text reading, 10% of idling and 5% of away mode, the power savings can be estimated to be 29%.

<table>
<thead>
<tr>
<th>Saccade Pattern</th>
<th>Viewing Mode</th>
<th>Luminance (cd/m²)</th>
<th>Lightness (%)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>idling</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Narrow, regular</td>
<td>text reading</td>
<td>27</td>
<td>75</td>
<td>103</td>
</tr>
<tr>
<td>Narrow, irregular</td>
<td>image viewing</td>
<td>64</td>
<td>100</td>
<td>350</td>
</tr>
<tr>
<td>Wide</td>
<td>away</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

4. Conclusions

We have proposed a novel approach to managing display power by using the user’s viewing status. It detects the user’s viewing status by using saccade frequency and amplitude only. An EOG circuit has been implemented to demonstrate its simplicity and efficacy.

5. References


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