June 2022

Machine Learning Driven Under Display Ambient Light Sensor Calibration

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ABSTRACT

An under-display ambient light sensor (ALS) can be employed in devices that have small bezels which cannot accommodate an ALS. However, the lux detected by an under-display ALS can deviate from the true lux levels of the environment because of the impact of the light from the display pixels. This disclosure describes the use of a calibrated machine learning model to obtain the true lux measurement for ambient light by adjusting the value measured by the ALS to compensate for the influence of display light.

KEYWORDS

- Ambient Light Sensor (ALS)
- Under-display ALS
- Lux measurement
- Light measurement
- Lux correction
- Light equalization
- Adaptive display
- Light equalization
- Ising model

BACKGROUND

Devices such as smartphones, tablets, laptops, etc. include an ambient light sensor (ALS) that measures the lux levels of ambient light in the vicinity of the device. The ALS can be employed for a variety of purposes including adaptive display features such as light equalization to adjust the display properties according to the lux levels of the environment near the device.

Accurate light equalization is important for boosting the realism of the device display. For instance, in a well-lit space, the display temperature can be made to adapt to the warmer colors of the lights. Features that use the ALS can be implemented via the device hardware, operating system, applications, web browser, etc.

The increasingly large size of the displays of many devices has led to reduction in the width of the bezel in which the ALS is typically placed. One option for placing the ALS in a device with thin bezels is to embed the ALS module under the display with a small aperture. However, such arrangement places the ALS in close proximity to the display, thus making it highly likely that the lux levels detected by the ALS are impacted by the changes in light levels caused by the display itself. If the impact of the light fluctuations from the display is not appropriately corrected, the lux measurement provided by the ALS can be different from the true lux levels of the environment. Such deviation can be nonlinear, based on varying lux levels of the display. Conventional brightness equalization performed using uncorrected lux measurements from an ALS placed under the display can result in a suboptimal viewing experience because of the nonlinear bias in the uncorrected lux measurement.

DESCRIPTION

This disclosure describes techniques to correct the influence of the lux variations induced by light fluctuations from a device display in the lux measurements obtained from an ALS module located under the display. The correction is derived by gathering lux information for the device display pixels that surround the under-display ALS module. Lux measurements of these pixels are obtained via a controlled brightness sweep through the lux space. A non-linear regression model built from the sweep data is employed to subtract bias in the ALS measurement that results from real-time changes in display brightness as indicated by the readings from the pixels. The correction is based on the linearity of light transport captured in the equation:

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LUX_measured(t) ~= Lux_environment (t) + f(display_brightness(t))
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As long as the time-varying function that captures the display brightness (the second term on the right of the above equation) is estimated with reasonable accuracy, subtracting the estimate from the lux measurement obtained via the under-display ALS can yield the real-world lux measurement without the influence of the lux variations of the display.

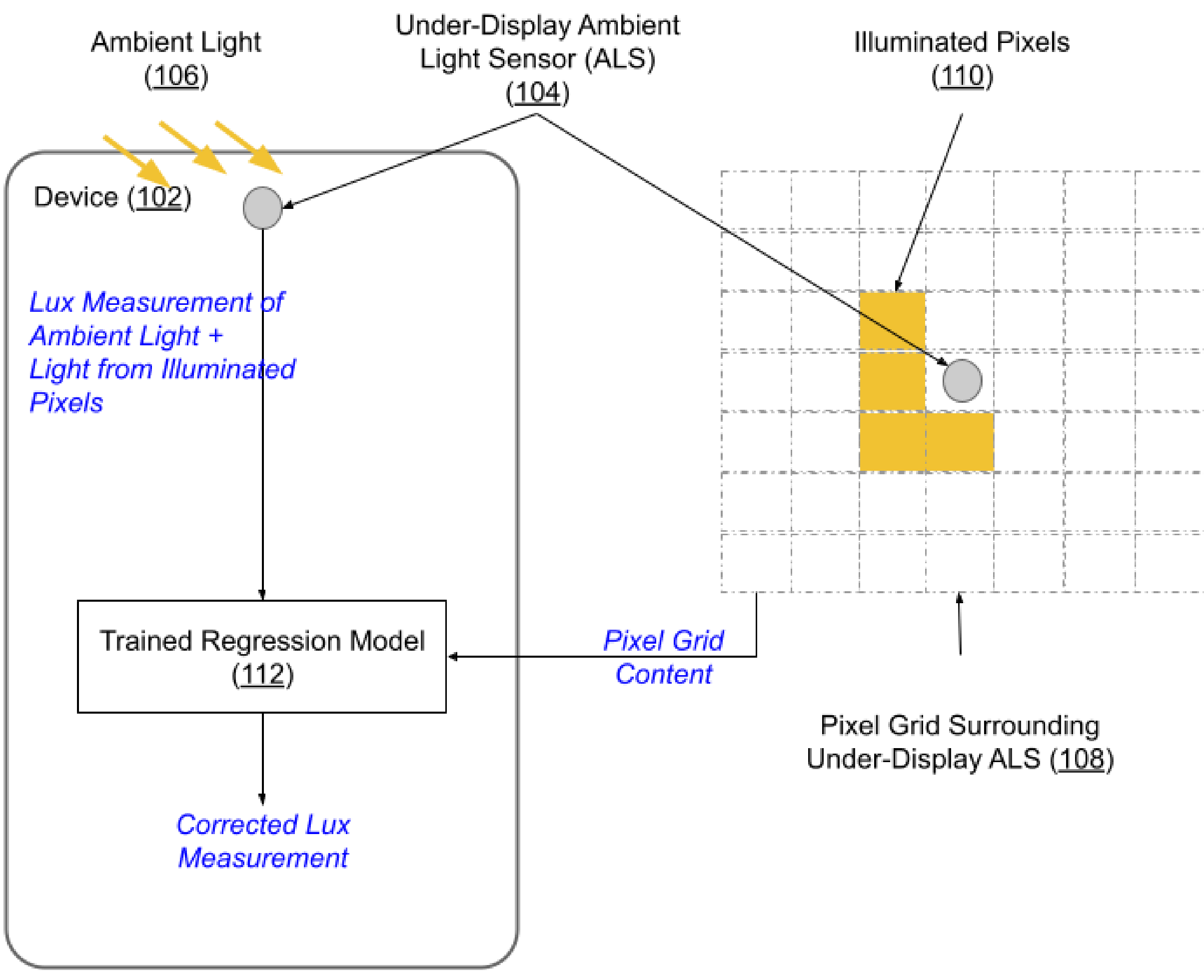

Fig. 1: Subtracting the impact of illuminated pixels that surround an under-display ambient light sensor

Fig. 1 shows an operational implementation of the techniques described in this disclosure. A device (102) captures light via an ALS placed under the device display (104). The lux measurement obtained from the ALS results from a combination of ambient light (106) and light from illuminated display pixels (110) in a grid of pixels surrounding the ALS (108). Based on the state of the pixels in the grid, a trained regression model (112) is employed to correct the lux measurement to match that only for the ambient light.

The influence of a display pixel on the lux measurement obtained from the ALS depends on the proximity of the pixel to the ALS. Light from pixels farther away register a lower impact for the same RGB value compared to ones immediately next to the ALS. Therefore, the correction is based on pixel illumination states of pixels located in a grid immediately surrounding the ALS.

For instance, Fig. 1 shows a grid patch of 7x7 pixels. The size of the grid patch can be set by the device manufacturer and/or determined dynamically, e.g., based on light conditions and application requirements at runtime. Regardless, the size of the pixel grid that is examined for applying the correction is reasonably small. This limits the number of weights required for operation of the model to a relatively small value, such as 10,000. The comparatively small values of the parameters ensure that the model can be run on hardware available on typical commodity devices, such as smartphones, to correct lux measurements in real time (e.g., at ~30 Hz). This is suitable for typical refresh rates of device displays and avoids visual lag in brightness adaptation per frame.

Even within the small grid of pixels surrounding the ALS, variability in spatial distance of each pixel from the ALS can result in variable impact on lux measurement even when the same number of pixels within the grid are illuminated with the same RGB values. For instance, the net lux measurement can be impacted differently if the four illuminated pixels were in a far corner of the grid away from the ALS rather than being next to the ALS as depicted in Fig. 1. Pre-defined display codes are used to train and calibrate the convolutional regression model employed for correcting the lux measurement. The calibration is designed to account for the variations in net and illumination effects of the patterns of pixels in the grid because of their spatial distance from the ALS.

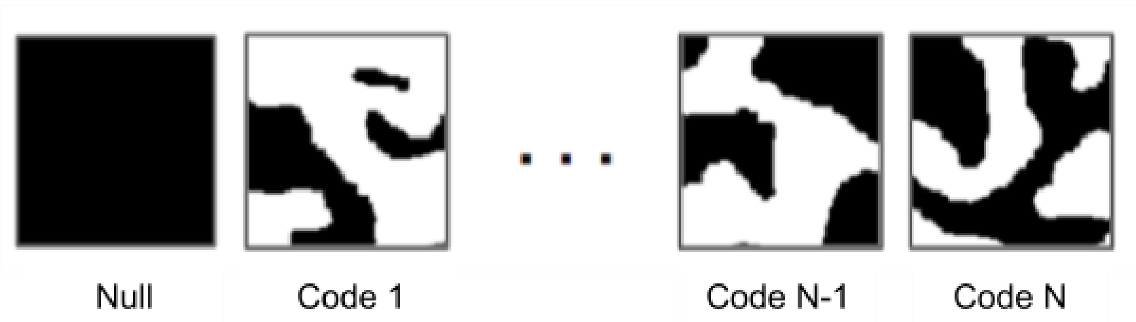

Fig. 2: Examples of codes used for model calibration

The calibration includes formation of a dictionary by displaying a finite set of local codes (shown in Fig. 2) on the pixels in the chosen grid. The codes are designed by employing a model simulator (e.g., Ising model simulator) to generate realistically random local image blobs at scale. Such models are superior to random codes per pixel because of their high pixel-to-pixel consistency akin to natural images. For instance, pixels in codes generated by a model have a high probability of having values close to those of its neighbors, instead of being completely random.

As seen in Fig. 2, in addition to the simulated codes, the set includes a null image with all pixels turned off. This code is used to obtain and subtract the baseline ALS measure to ensure that calibration is based purely on pixel state and not affected by environment variations. Each code image in the dictionary is linked to a corresponding lux measurement value. The dictionary is used as training data for the convolutional regression mode to learn the mathematical function that can be applied in the operational phase to any given code image of the grid pixels to derive the likely lux measurement corresponding to it.

Calibration and training are typically a one-time operation that can be performed when the device is first set up. However, recalibration can be performed as necessary, e.g., due to changes in device hardware and/or software. The trained model obtained based on the calibration can be saved to persistent local storage and used to adjust the ALS sensor measurements during use of the device.

Implementation of the techniques described in this disclosure can improve the accuracy of lux measurement of ambient light by ALS modules placed under the device display. With calibration as described herein, the obtained measurements have minimal influence of light emitted by the display pixels surrounding the ALS. The ability to place an ALS module under the display instead of in the device bezel allows reduction in the dimensions of the bezel, thus making it possible for device manufacturers to provide larger device displays without increasing the physical size of the device.

CONCLUSION

An under-display ambient light sensor (ALS) can be employed in devices that have small bezels which cannot accommodate an ALS. However, the lux detected by an under-display ALS can deviate from the true lux levels of the environment because of the impact of the light from the display pixels. This disclosure describes the use of a calibrated machine learning model to obtain the true lux measurement for ambient light by adjusting the value measured by the ALS to compensate for the influence of display light.