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Automatic Display Brightness Control with Multiple Sensors

Jung Ook Hong

Yi Zhang

Andrew Lehmer

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Abstract:

This publication describes a user equipment (UE), such as a smartphone, that supports automatic display brightness control by using multiple sensors and interpreting the context in which a user utilizes the UE. The UE may automatically control the display brightness using different methods. In one embodiment, the UE may measure the ambient light (lux) using a front-facing ambient-light sensor (ALS) and a rear-facing ALS. In one embodiment, in addition to the front-facing and rear-facing ALSs and/or front and rear cameras, the UE may utilize edge ALSs. In one embodiment, in addition to the front-facing and the rear-facing ALSs, the UE may use a combination of other sensors, such as proximity sensors, a radar-based sensor, or accelerometers to determine the orientation of the UE (*e.g.*, laying on a flat surface) and ignore measurements from one of the ALSs. In one embodiment, in addition to ALSs and/or other sensors, the UE may also use the context in which the user is using the UE, such as what application software the user is currently using. In one embodiment, the UE may use an advanced sensor-fusion algorithm that takes raw red, green, and blue (RGB) data from the front and rear cameras, combines them with the UE's orientation, estimates the level of ambient lux, and automatically controls the display brightness without using ALSs.

Keywords:

User equipment, UE, display brightness, display brightness control, luminance, luminous flux, lux, RGB, front camera, rear camera, ambient-light sensor, ALS, light sensor, accelerometer, proximity sensor, hardware abstraction layer, HAL, sensor fusion algorithm.

Background:

Various user equipment (UE), such as smartphones, tablets, notebooks, and the like, support automatic display brightness control to provide a better user experience and save the UE's power. The brightness control works by measuring the luminous flux (lux) using a front-facing ambient-light sensor (ALS) of the UE. As described herein, brightness refers to the perceived brightness of an object by a user, the ALS, or the UE. A low brightness may refer to a lux level that is less than a predefined threshold level, such as approximately 50%, 40%, 25%, 15%, and so on. This predefined threshold may be set by the UE manufacturer or defined by a setting selected by the user. A high brightness may refer to a lux level that is greater than a predefined threshold level, such as approximately 50%, 60%, 75%, 85%, 95%, or 100%.

This approach functions well in situations where the ambient light that is being measured by the front-facing ALS is static, and a light source (*e.g.*, a lamp, the sun) is not shining directly onto the field of view of the front-facing ALS. There are common situations, however, where the user may observe a static ambient light, but the front-facing ALS measures large lux changes, as illustrated in Figure 1.

Figure 1

Assume Tom is using his smartphone to communicate with his friends. As Tom walks into his kitchen, the overhead light shines directly onto his smartphone's front-facing ALS, as is illustrated in Figure 1. All of a sudden, the front-facing ALS senses an increase in lux, and the smartphone automatically increases the display brightness. Then, Tom's head casts a shadow onto the front-facing ALS, causing it to sense a decrease in lux, and the smartphone automatically decreases the display brightness. Tom, however, perceives a static ambient light and does not expect the smartphone's display brightness to fluctuate. In addition, Tom may not be aware how the smartphone changes the display brightness, and he may wonder whether his smartphone is not functioning properly. As a result, Tom's user experience suffers due to the way the smartphone controls the display brightness.

Therefore, it is desirable to have a technological solution that can enable the UE to adjust the display brightness according to the ambient light that the user is experiencing when using the UE.

Description:

This publication describes a user equipment (UE), such as a smartphone, a tablet, a notebook, and the like, that supports automatic display brightness control by using multiple sensors to enhance user experience and conserve the UE's power.

Recalling the example illustrated in Figure 1, Tom's smartphone uses a single front-facing ambient-light sensor (ALS) for measuring the luminous flux (lux) to determine the ambient light that the user is experiencing when using the UE. Tom's smartphone performs adequate automatic display brightness control in most cases, but the smartphone misinterprets situations when a light source is occasionally shining directly onto the field of view of the front-facing ALS or when

Tom's head casts a shadow onto the front-facing ALS. To mitigate this problem, in one embodiment, the smartphone may use a front-facing ALS and a rear-facing ALS to measure the ambient light that the user perceives, as is illustrated in Figure 2.

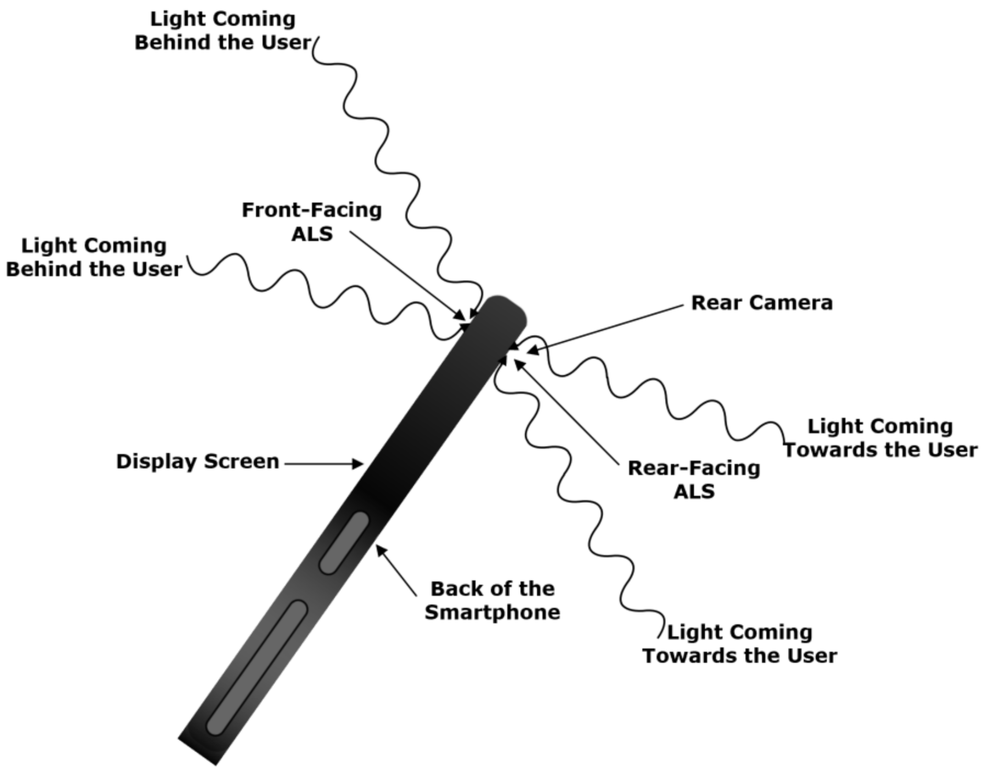


Figure 2

Figure 2 illustrates a partial side view of a smartphone. Beside other hardware, the smartphone has a display screen, a rear camera, a front-facing ALS, and a rear-facing ALS. In the embodiment illustrated in Figure 2, the rear-facing ALS is embedded on the back of the smartphone near the rear camera. A software algorithm controls the display brightness by processing lux measurements from the front-facing ALS and the rear-facing ALS. Since the two ALSs measure lux from opposite directions of the smartphone, it is less likely that both ALSs will face lux fluctuations that are not representative of the overall ambient light. Light fluctuation may be caused by a lamp shining behind or towards the user, a shadow, a reflecting surface (*e.g.*, mirror, window glass, water), color surfaces (*e.g.*, black asphalt, white walls), and so forth. Differently said, if one ALS senses a lux change, while the other ALS does not sense a lux change, the software algorithm does not trigger a change in the display brightness. The software algorithm triggers a change in the display brightness only when both ALSs sense a change in lux.

It is worth noting that some smartphones may already have a front-facing ALS and a rear-facing ALS that are used for different functionalities. For example, some smartphones may use the front-facing ALS to control the display brightness and may use the rear-facing ALS to control the camera exposure-time, a flash, or other camera features. Therefore, the embodiment illustrated in Figure 2 enhances display brightness control without adding hardware—the smartphone uses the rear-facing ALS for more than one functionality. To utilize the rear-facing ALS to support more than just camera functionalities, the smartphone decouples the rear-facing ALS from the camera hardware abstraction layer (HAL), as is illustrated in Figure 3.

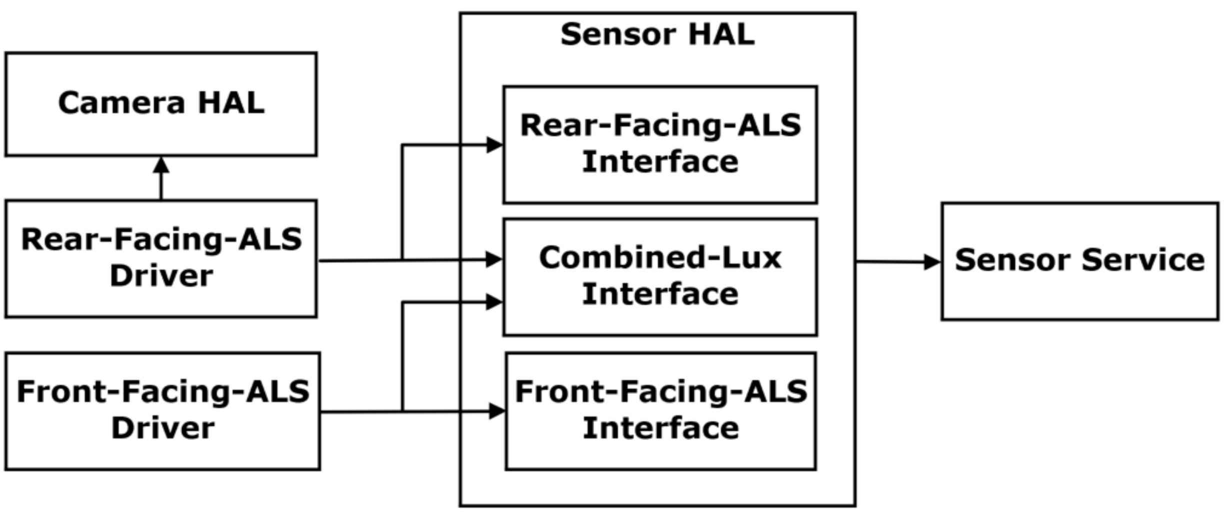


Figure 3

As is illustrated in Figure 3, to use the rear-facing ALS readings for automatic display brightness requires the following changes along the stack between the rear-facing ALS driver and the operating system's (OS) sensor framework:

- Decoupling the rear-facing-ALS driver from the camera HAL;

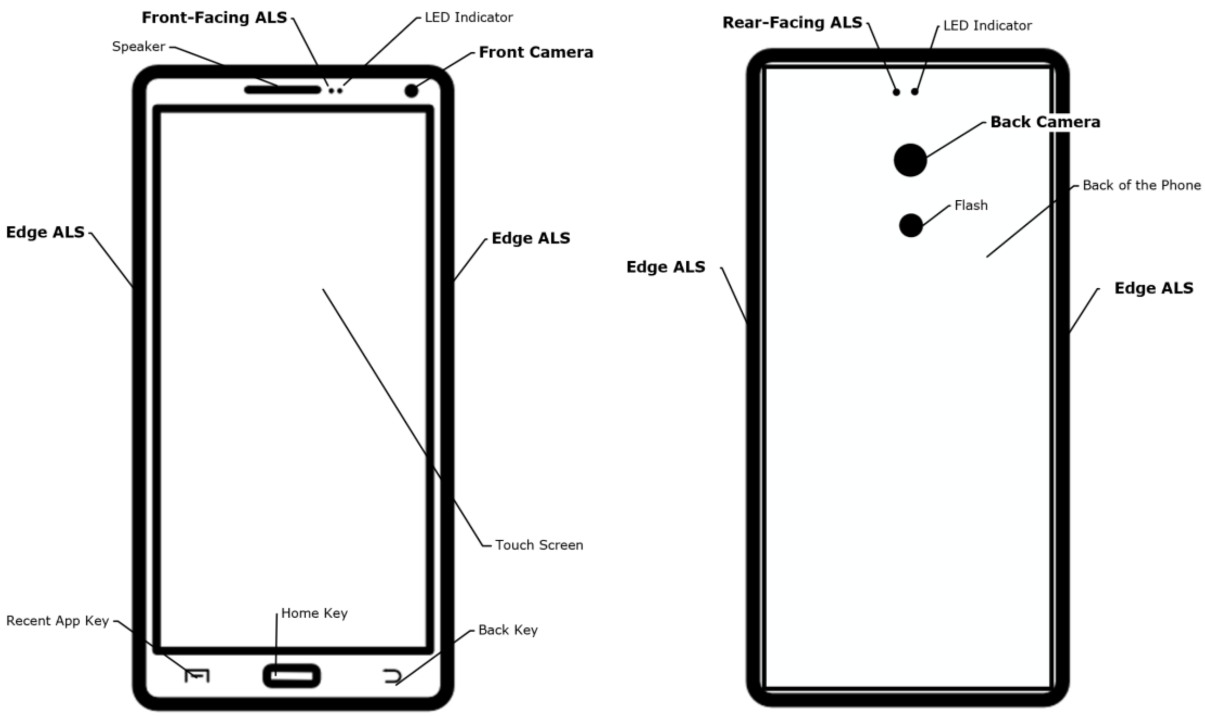
- Interfacing the sensor HAL with the rear-facing ALS; and
- Creating a virtual-lux sensor (combined-lux reading) that combines readings from the front-facing ALS and the rear-facing ALS into the sensor HAL.

In the design illustrated in Figure 3, instead of the camera HAL requiring sole “ownership” of the rear-facing ALS, the rear-facing ALS uses the rear-facing ALS driver to simultaneously provide readings to multiple UE functionalities. This way, the camera HAL retains access to the rear-facing ALS without interference from the requests made by the sensor HAL. Also, since the camera HAL is decoupled from the rear-facing ALS driver, the rear-facing ALS-related logic of the camera HAL is modified to use an application process interface (API) provided by the rear-facing ALS reading.

The sensor HAL in Figure 3 is a collection of sensor adapters between sensor hardware embedded in or on the UE and the OS sensor framework. Unlike other sensor adapters within the sensor HAL, the combined-lux reading is a “client” of the front-facing ALS and the rear-facing ALS. The combined-lux reading combines readings from the front-facing ALS and rear-facing ALS.

UE manufacturers often integrate accelerometers, gyroscopes, magnetometers, barometers, global navigation satellite system (GNSS) technology (*e.g.*, global positioning satellite (GPS)), proximity sensors, ambient-light sensors (ALS), touchscreen sensors, biometric sensors, heart-rate sensors, thermometers, humidity sensors, radar technology, cameras, microphones, and various other sensors in or on the UE, which enhance the user experience and may play a role in the functionality of various UE features and application software. Therefore, it may be advantageous for the smartphone to use more than just the front-facing and rear-facing ALS sensors to control the display brightness.

In one embodiment, in addition to or instead of the front-facing and rear-facing ALSs and/or front and rear cameras, the UE may utilize edge ALSs, as is illustrated in Figure 4.



A) Front-facing smartphone **B) Rear-facing smartphone**

Figure 4

In addition to or instead of the ALSs illustrated in Figure 2 and Figure 3, the UE may utilize edge ALSs, as is illustrated in Figure 4. The UE design illustrated in Figure 4, can sense a more representative ambient combined-lux reading. For example, if the rear-facing ALS senses a decrease in lux, but the front-facing and edge ALSs sense no change in lux, the UE can ignore the rear-facing ALS reading altogether.

In one embodiment, in addition to the front-facing and rear-facing ALSs, the UE may use a combination of different sensors, such as proximity sensors, a radar-based sensor, accelerometers, or gyroscopes, to determine the orientation and the location of the UE in relation to the user. For example, the user may place the smartphone on a flat surface (*e.g.*, a table) while using the smartphone. In that case, the UE ignores readings from the rear-facing ALS and uses only the front-facing ALS reading to control the display brightness.

In one embodiment, in addition to ALSs, accelerometers, gyroscopes, magnetometers, proximity sensors, radar-based sensors, and so forth, the UE may also use the context in which the user is using the UE, such as what application software is the user currently using, as is illustrated in Figure 5.

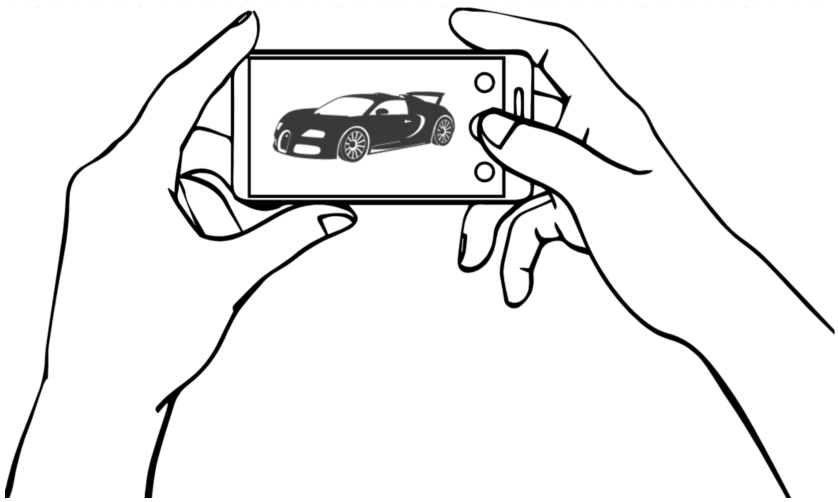


Figure 5

Assume Ben is playing a car-racing video game using his smartphone. Ben is holding the smartphone lengthwise to control the steering of the race car, as is illustrated in Figure 5. Ben's smartphone may use accelerometers and gyroscopes to enable Ben to steer the race car and may use a front-facing ALS and a rear-facing ALS to automatically control the brightness of the display. Ben's hands, however, may block one or both ALSs as he plays the game. In this context, the smartphone ignores ALS readings and keeps the display brightness constant.

Embedding multiple sensors in or on the UE is expensive and takes valuable "real estate." Therefore, in one embodiment the UE may use an advanced sensor-fusion algorithm that takes raw red, green, and blue (RGB) data from the front the rear cameras, combines the new RGB data with the UE's orientation, estimates the level of ambient lux, and automatically controls the display brightness. In this embodiment, the UE manufacturer can remove both ALSs and reduce the bezel size and the number of embedded sensors.

In conclusion, using multiple sensors and interpreting the context in which a user utilizes the UE helps to automatically control the UE's display brightness, enhances user experience, and conserves the UE's power.

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