Adaptive Display Luminance Control for Optimized Contrast Ratio

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Abstract - **The new generation displays are loaded with several new features to make these systems more user-friendly. There are several attributes of a display such as resolution, luminance and contrast levels, refresh rate, etc. which decides its rating and application. These systems with the human eye features like adaptive display luminance control (ADLC) under varying ambient luminance conditions add more challenge to design of display systems. The ADLC can be achieved by varying the display luminance according to the ambient luminance level. In this paper, various parameters which are important for adaptive luminance control have been discussed. Various types of light sensors, methodology and required parameters have been discussed in detail for realizing the display luminance adaptively while maintaining an adequate contrast ratio in real time.**

Keywords **– Luminance, Contrast, Viewing area, Display devices, Adaptive Display Luminance Control**

I. Introduction

The spectral characteristics play a major role in rating of a display system. In commercial and many of military applications, the display information is displayed in the colour format. However, there are few applications in which still the monochrome displays are used [1, 2].

A high contrast ratio is a desired aspect of any display devices to provide maximum comfort to the viewer. This feature is not only required in normal commercial applications like consumer televisions but they are specifically acquire more importance when talked in terms of industrial, military and aviation display applications. The luminance in any display application is generally provided with a manual control to set its value to a comfort zone. There can be an adaptive adjustment of the luminance coupled with the light sensors and the manual luminance and the contrast control [1, 2].

II. Discussion on Adaptive Display Luminance Control (ADLC)

The luminance and the contrast parameters are the prime attributes of a display quality which decides its video quality assessment by the user. While the contrast of a video is controlled by the signal strength, the luminance is its DC level with respect to a mean level around which the video signal is varied. The contrast of the video signal is decided by its signal strength and its effect is manifested in the display quality through image sharpness. The luminance control on the other hand will control the luminance level of the display information as well as the background if the image is written in raster fashion. The luminance control can be controlled adaptively based on the ambient lighting with the aim of user being provided with the comfort of adaptive variation in display luminance on the display surface against the varying ambient luminance. This is regarded as the 'Adaptive Display Luminance Control (ADLC)' [1-3].

Ambient light can change rapidly during fast movement of a surface transport vehicle like car, truck, bus, etc. or while an aircraft is carrying out maneuvers. In such cases, where displays used for providing useful vehicle and environment information are based on AMLCDs and having an opaque background, coping up with the dynamic ambient luminance change is relatively easy though an adaptive luminance control mechanism in such cases will always be beneficial. This is due to the fact that with such mechanism, user will not be required to adjust the luminance manually once set initially. The situation is compounded while using displays like head-up displays or helmet mounted displays where display luminance required is very high and ambient light change directly affect the visibility of the display. The adaptive luminance control would help in reducing high workload during the displays usage in aviation cockpits or for surface transport unless a single manual setting is found to be adequate for the high workload phase of flight. Such kind of situations is faced when vehicle is driven at high speed in high traffic situation or when an aircraft is doing maneuvers, landing or takeoff. The change in luminance level must result uniform adjustment of the relative luminance of each displayed parameters [1, 2, 4, 5]

III. ADLC Issues and Parameters

The key characteristics like contrast, accommodation, luminance, and viewing area, etc. are important and must be uniform for the displays used in any cockpit. When seen by both the eyes from any off-center location, non-uniformities in the display characteristics should not result noticeable differences [1, 2].

There are various attributes of the display luminance which are important to grade them as per the requirement. Luminance is the number of candelas/unit surface area of a source. Here, the surface area is the projected area of the actual surface in the viewing direction. It is used to characterize reflection and emission from flat diffuse surfaces. Luminance is a measure of the luminous density in a particular direction and characterizes total light passing through or emitted from a given area and falling within a given solid angle [1, 2].

The light output from the display source need to be measured and quantified. Commonly, lumen is used as a measure of light output. Accordingly, light sources are categorized with their output rating in lumens. Light intensity measured at a surface on a specific location is called illuminance. Thus, illuminance is the total luminous flux incident on surface/unit area. It indicates about the amount of incident light illuminating the surface. It is measured in foot-candles which is defined by lumens per square foot. Lux is the metric unit used for illuminance, designated in lumens per square meter. It is a measure of the intensity of the light that hits or passes through a surface as seen by the human eyes. The foot-candles to lux conversion is done by multiplying foot-candles by 10.76. The measurement of light is also done through measuring luminance. This refers to measurement of light emitting from a surface in a specific direction. It considers the illuminance on the surface as well as reflectance of the surface. As far as humans are concerned, they do not see illuminance. They see luminance. Hence, the amount of light emitted into the space as well as the reflectance from the surfaces in the space has an effect on our ability to see. The suitable average light level for a particular case depends on light or display source efficiency, lumen output, reflectance of the nearby surfaces, effects of light losses, area, availability of natural light, etc. [1, 6-8]

The parameters which may are important from the luminance assessment are: glare, uniformity of illuminance and the color rendition. To get an idea of luminance levels, comparative figures under various conditions is given. An illuminance of order of 10^{-4} lux is there in a moonless or overcast night sky having only starlight, an illuminance of about $2x10^{-3}$ lux is there in moonless clear night sky with airglow, an illuminance of about 0.27-1.0 lux is there in a full moon on a clear night, an illuminance of about 3.4 lux is there in civil twilight in a clear sky, an illuminance of about 40-50 lux in a living room, an illuminance of about 60-80 lux in an office way, an illuminance of about 80-100 lux in a dark overcast day, an illuminance of about 300-500 lux in office, about 350-400 lux during sunrise or sunset on a normal clear day, an illuminance of about 900-1000 lux during an overcast day or studio, an illuminance of about 10000-30000 lux during full day light, and an illuminance of about 30000-130000 lux in direct sunlight [2, 6, 7].

The luminosity function peak is at 555 nm (corresponding to green wavelength) and the human visual system is found more sensitive to this wavelength than any other wavelength. For monochromatic green light of this wavelength, value of the irradiance required to make one lux is at minimum level is at 1.464 mW/m^2 corresponding to 683.002 lux per W/m^2. Other wavelengths of visible light produce fewer lumens per watt. The luminosity function falls to zero for wavelengths outside the visible spectrum. For a light source with mixed wavelengths, in order to appear reasonably white, a light source cannot consist solely of the green light to which the eye's visual photoreceptors are most sensitive, but must include a generous mixture of red and blue wavelengths to which they are much less sensitive. In reality, individual eyes vary slightly in their luminosity functions [6, 7].

Contrast is other main parameter which is controlled by the ADLC. The measure of readability against a background is defined by the contrast ratio. It is the ratio of the sum of the luminance of the display field and of ambient luminance with the ambient luminance. It may also be defined as the ratio of luminance of the brightest white with the darkest black. When the display contrast ratio is between 2 and contrast ratio between 1.4 and 2, the display contrast ratio is reasonable. For range 1.2 to 1.4, the display is just viewable. The contrast ratio beyond 5 does not provide comfortable view and hence adaptive luminance variation with the changing ambient conditions is even more important [1, 7].

For the higher range of luminance, the display luminance needs to significantly higher to have an adequate contrast ratio. To have reproduced contrast ratio and better quality of picture it is important to set black level precisely. The visual display device needs to be configured in such a way that with ambient light varying continuously, the display luminance should have value a comfortable view with adequate contrast so that the pilot (in case of avionics) and driver (in case of an automobile) are comfortable while viewing against the ambient of varying luminance. Contrast enhancement techniques are widely used to improve the image visual quality. The variance in luminance reflected from two neighboring surfaces results in contrast between the image surfaces. Greater contrast will make it easier to identify and distinguish objects in an image. Thus object contrast is a vital factor in perception of the image visual quality. It is useful in object recognition and image analysis [6, 7, 9].

The display luminance of avionics systems providing see through capabilities like head-up displays or active matrix liquid crystal displays like multi-function and standby displays should be high enough. The dynamic varying ambient lighting is equivalent to the environment in which such high luminance displays are desired to be operated, i.e., the image on these displays should be able to be seen against high ambient light or at low ambient luminance light under which these are intended to be operated. They should be able to display minimum number of gray shades. Similarly, the contrast between continuous gray shades must be adequate enough to make them detectable with appropriate display luminance and contrast settings. The head-up displays or other AMLCDS based displays should be able to provide a dim and low background free display in night or low lighting. A least number of shades of gray specified should be visible and the blank areas of the video should not be visible. The variation in luminance in any two locations within the monocular field of vision or 10˚ of each other should be within ± 35% [1, 2, 10].

The basic requirements of ADLC include [1-3, 7]:

- The adaptive luminance control mechanism is required to be fast enough so as to have immediacy in the display luminance value. This will avoid discomfort to the pilot when the fast changes in the ambient luminance.

- The user should be able to adjust the display luminance through by user controlled potentiometer. The amount of this control should be appropriate so that its effect is not suppressed by the change due to ambient lighting nor it should have so much variation that at some point of potentiometer setting, the ADLC effect is not significant.
- Adaptive display luminance control varies the luminance of the display based upon ambient light as sensed by an ambient light sensor in order to achieve optimized contrast ratio for good image quality. To produce a trace of constant luminance the beam current must vary with the deflection speed.
- The ADLC is required to vary the display luminance from minimum to maximum luminance at a low and high ambient lighting respectively.
- The dynamic range of HUD luminance must provide display readability in ambient lighting from 0 fL to 10,000 fL. In certain extreme conditions, head-up display usage becomes impractical, for example, when flying directly toward the setting sun. In such condition, transition to head-down flight display must be made.
- The main test is to make the system response in real time mode and provide good contrast ratio of the scene or symbology against varying ambient light condition.
- The light sensor should have appropriate incident luminance range and should be positioned at correct location to have full light incident.

IV. ADLC Sensor and ADLC Realization

The basic function of ambient light sensing is achieved through a photo-sensors device. Photo-sensors or photo-detectors are sensors of light. There are various kinds of light sensors with each working in a different way. Active pixel sensors are image sensors and are used in mobile phone, web and some digital cameras. An image sensor generated through a CMOS process also called as CMOS sensor can be used in place of charge coupled device (CCD) sensors. The CCDs are meant to record images of digital photography, astronomy and digital cinematography. Particle detector is a also a sensor based on light detection used to identify and track elementary particles. The chemical detectors can use a silver halide molecule which is split into an atom of the metallic silver and halogen atom. Cryogenic detectors are very sensitive and can measure the energy of X-ray, infrared and visible photons. LEDs in reverse bias mode act as photodiodes. Optical detectors are generally quantum devices and based on the principle of individual photon producing a discrete effect. Photo-resistors or light dependent resistors change resistance as per the incident light intensity. The resistance of Photo-resistor reduces with the increasing intensity of the incident light. The photovoltaic cell produces a voltage. They supply an electric current when light is incident on it. Photodiodes are also kind of light sensors which can work in photoconductive or photovoltaic mode. Photomultiplier tubes are based on photocathode responsible for emitting electrons when exposed to light. The electrons are subsequently amplified by a dynodes chain. Phototube is another type having a photocathode responsible for emitting electrons when illuminated. Phototransistors act like amplifying photodiodes. Quantum dot photoconductors can work on visible as well as infrared wavelengths.

Light sensors are continuously used in day to day research. They are used in simple science as well as in the recent breakthroughs in medicine, robotics, and space. For example, robots can be based on light sensors to navigate, detect objects. This is done by sensing how light bounces from them.

Devices that use these sensors have many applications in scientific uses but have implementations even in things encountered by people in their daily life. Light sensors are also used in security and safety devices such as a burglar alarm, garage door opener, etc. These devices work by exposing them with the light shifting them from one sensor to another. Many electronic systems like computer, television, wireless phones, etc. use light sensors to automatically adjust the screen luminance according to the ambient light. They can detect the level of light in a room and accordingly can raise or lower the luminance to a comfortable level. Light sensors can also be utilized to automatically switch ON the lights. The scanners found in shops are based on light sensor technology. The scanner emits the light which in turn illuminates the barcode. This is then read and decoded through a sensor. Quick response codes also work in the same way although they comprise more information. They can be read using a smartphone if it is compatible with the code reader.

While some products based on the light sensors are in existence for some time, these sensors have become continue to become even more relevant, particularly through infrared sensing technology. The heat is emitted by the warm blooded animals which can be read as infrared light and detected through infrared light sensors. Motion dependent light sensors based on infrared are used in grocery stores, for example. When a shopper comes near display case, the light sensor in the display case identifies the movement of the shopper followed by turning on the lights. These lights become dim when no shopper is there near the display case. Thus the shop is able to save the energy costs. Such kind of arrangement is used by several retailers and business establishments to control the room lights which are used continuously such as conference rooms, restrooms, etc.

The luminance sensor is the prime element for realizing real time adaptive luminance control for various types of displays through ambient light compensation. These sensors are selected as per the application. Photodiodes or light photo-resistors are generally used as light sensors. The photodiodes provides voltage output with change in ambient light. While in photo-resistors, variation in the ambient light is sensed as proportional resistance change. All the light sensors saturate when light falling on them is more than its maximum allowed light input range. If the range of luminance is more, the ambient light falling on the sensor can be restricted using optical neutral density filters. These filters can be built with different attenuation factors.

The output of the ambient light sensor is given as input to the microcontroller through analog to digital converter aids in making a decision whether to increase or decrease the display luminance. This also necessitates that the light sensor should be located at a suitable location such that light captured by the light sensor is same as the actual ambient light.

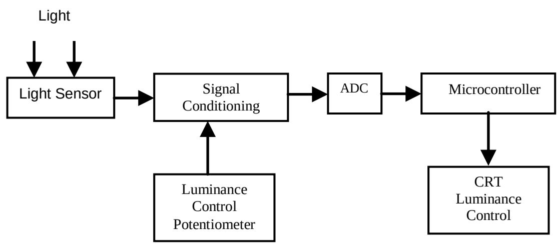

Figure 1: Realization of ADLC

The implementation part involves sensing the incident light which is supposed to be encountered by the display device in actual application environment. The selection of sensor is based on the lighting the display is supposed to be subjected to. The package of the sensor is decided based on the space available for its mounting and the surface area required in maximizing the light input on the sensor surface. The type of sensor is based on the sensitivity and range required. If the light incident on the sensor is beyond its range, the optical neutral density filter of the required attenuation would optimize and scale the light incident down. The detectors which are required to be used ADLC implementation depend on the end application. The detector which can sense the wide range of light from 5 lux to 1,00,000 lux are desired for see-through displays like head-up displays. Though the ADLC could also be implemented in a crude way through approximation of the user controlled and the sensor output by analog method, but for more smooth operation, operating in digital domain is desired. Accordingly, the sensor as well as the user controlled potentiometer output after suitable signal conditioning to the appropriate voltage range is digitized. This is achieved through analog to digital converter. Its resolution will decide the smoothness of detection and subsequent final variation. Generally 10-bit ADC is adequate but 12-bit ADC gives very good results. The two digitized conversions are then routed to the intelligent device which may be a microprocessor or a microcontroller. The required algorithm could be based on linear approximation on experimental data, piecewise linearization of the luminance curve, look table method, and real time algorithm for high, mid and lower range of ambient lighting. The choice of the algorithm is based on the extent of smoothness and variation required. The real time operation requires that the processor device used is configured to appropriate clock speed. The lower speed may result in delayed or the step variation. However, there is an additional control to disable and enable the ADLC feature along with the option to reduce the sensitivity as well as the range.

The adaptive control in case of various kinds of displays such as AMLCD, Organic light emitting diodes, Plasma displays, etc. will mean brightened section pixels have more DC level. In case of a cathode ray tube based display, the display can be obtained through stroke or the raster scanning. In stroke scan, the display is obtained by scanning the beam point to point on the CRT surface. In the raster scanning, the display is obtained by scanning 625 (or 525) lines horizontally standard and vertical scan rate of 50 Hz (or 60 Hz) depending on the raster standard being employed. The stroke scan mode along with adaptive display luminance control sets the symbol luminance to appropriate level. The same in raster scan mode results in a desirable contrast.

In cathode ray tube, electron beam released from negatively charged electrodes strike phosphors at the front of the tube causing them to emit light and create image. The video can be applied at cathode with a positive polarity video or at the grid with a negative polarity video. While display contrast depends on the video signal strength, the luminance depends on the video signal dc level. By suitably varying the DC level, the luminance can be adaptively varied to have adequate contrast in varying ambient lighting.

V. Conclusion

The luminance and the contrast parameters form one of the prime parameters to assess any kind of display. The luminance control controls the luminance level of the display information. The display adaptive luminance variation provides efficient control of the display luminance. The ADLC mechanism provides an effective display contrast when ambient light vary rapidly as can happen during fast movement of a surface transport vehicle like car, truck, bus, etc. or while an aircraft is carrying out maneuvers. The adaptive control of luminance keeps the average contrast of the reproduced image constant such that viewer is comfortable while viewing against the ambient of varying luminance.

The basic requirement of ADLC is the light sensor and the suitable algorithm. The light sensor selection is based on the range of ambient lighting, space required for its installation, surface area and sensitivity, however innovation of putting neutral density filter for attenuating the light input to light sensor. The algorithm can be based on linear approximation on experimental data, piecewise linearization of the luminance curve, look table method, and real time algorithm for high, mid and lower range of ambient lighting. The resolution of variation, real time operation and the operation range are the other attributes of the ADLC realization

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