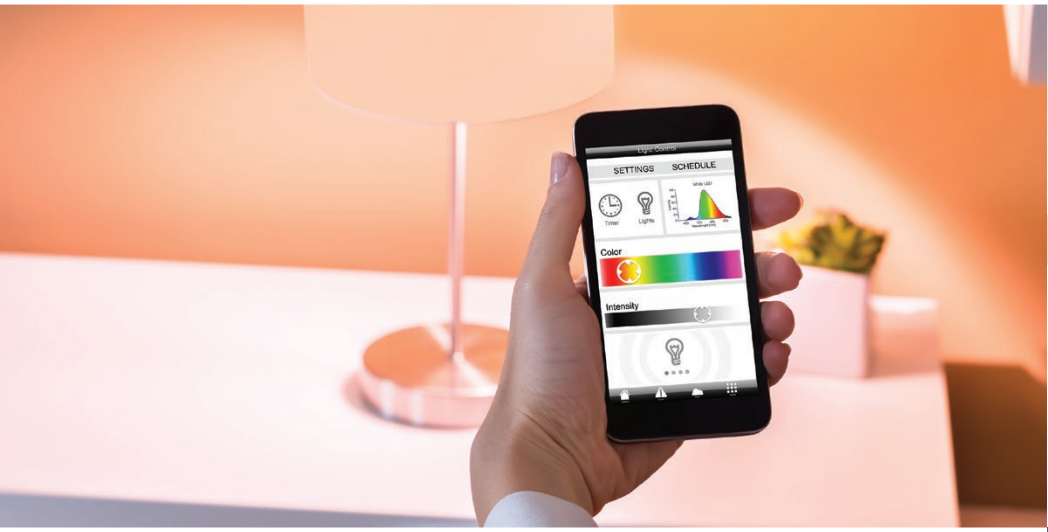
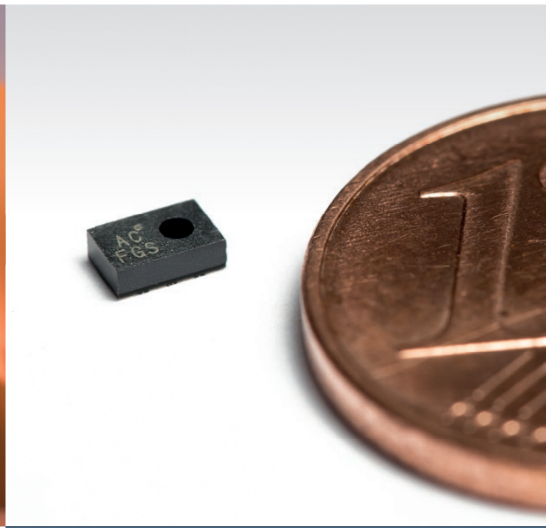
ams.com

White Paper

Chip-scale spectral sensing: understanding the new uses for ultra-precise light-source measurement





By Kevin Jensen

Sensing is life.

How manufacturers can use the spectral information which image or color sensors cannot see to create better performing, safer or more enjoyable products

By Kevin Jensen

Introduction

Every professional photographer understands intimately the effect of different sources of illumination on the quality and fidelity of a photograph's rendering of color. White-point balancing – compensating an image's treatment of color for the distorting effects of a light source – is one of the core functions of advanced photographic equipment.

In fact, however, light sources can have a marked effect on many other areas of modern life beyond photography. Supported by accurate measurement of ambient light sources, consumers can enjoy:

- Better display and camera performance in devices such as computers and tablets
- More environment-aware functioning in wearable devices
- Healthier and more comfortable lighting
- More robust operation of safety and surveillance equipment

To implement accurate light source measurement in consumer products, device OEMs need to implement colorimetry with optoelectronics circuits that conform to tight constraints on space and cost.

This white paper examines the options available to device OEMs today for light source measurement, and describes the new opportunities that chip-scale spectral sensing provides for adding value to consumer, professional and industrial products.

Understanding the impact of the light source on human visual perception

Everyone is familiar with the effect which distorting light sources have on our perception of color. For instance, incandescent sodium streetlights emit a strongly orange-hued light under which it is almost impossible to distinguish most colors. Under sodium light, a scene becomes flattened, and the viewer is deprived of huge amounts of visual information that is available in daylight. Similarly indoors, fluorescent lighting and low-cost LED light sources distort color and wash out the rich palette perceived under natural sunlight.

This concept of distortion implies that there is a 'perfect' light source, or that some light sources are more 'true' than others.

In fact, every light source has its own distinct signature. Daylight itself is infinitely variable. The sun's light is more warm-white in the morning and cool-white around noon, and becomes progressively more golden towards dusk. The nature of sunlight varies not only with time but with place: the color content of sunlight is affected by its path through the Earth's atmosphere. This helps to explain why painters have prized the special quality of the light in places such as St Ives in Cornwall, UK, or on the Mediterranean coast of France. This is not some artistic oddity – the light really is different in different places.

And since we see the color of an object when light from an external source is reflected from the object to our eyes, if the characteristics of the light source change, the object's color will also appear to change.

There is, then, no such thing as a single perfect light source under which the true color of any object will be rendered. Nevertheless, humans instinctively know that a light source such as a fluorescent lamp does not render color truly. In fact, evolution has conditioned the human visual perception system to operate optimally in normal daylight. And this has led industry to define daylight-like reference light sources, the spectral characteristics of which are intended to exactly match those of 'average' daylight. These reference sources are specified at various color temperature points. The D65 reference (the D stands for Daylight), for instance, is a representation of daylight with a correlated color temperature (CCT) of 6500K – a typical value on a bright sunny day at noon.

Viewed under D65 light, colors will be rendered in a way that the average human will generally perceive as 'true'.

Why photographers care about light source measurement

In general, a photographer's purpose in capturing a photographic image is to record a true visual representation of the scene in the viewfinder. For artistic reasons, photographers might choose to apply graphical treatments to the raw image to produce some desired effect, but photographers want the raw image to accurately record the scene. This includes accurately recording the color of the objects in the scene.

The camera's image sensor detects the light reflected from objects in the field of view. So if the light source is, for instance, an LED lamp with a relatively low Color Rendering Index (CRI) rating of 80, the image sensor will 'see' distorted colors.

This is a problem for camera manufacturers, because today's consumers are discerning users, particularly of the cameras embedded in smartphones. In fact, the camera is today often the biggest point of differentiation between one smartphone and a competing product at a similar price point.

So camera manufacturers have over many years refined the techniques used to compensate for the distorting effect of the light source on the camera's output. This process of 'automatic white balancing' started with the camera's image sensor itself. This is an RGB optical sensor: a semiconductor device containing three types of pixels which have their peak sensitivity in broadly the red, green and blue portions of the visible light spectrum.

An object emitting a combination of red, green and blue wavelengths appears to the eye as white. In any scene containing a substantially white object, the RGB sensor can use this white as a reference point and adjust the treatment of the other colors in the scene accordingly – so, if the white is a relatively yellow white, the camera's software 'brain' will assume the light source is a yellow hue, and adjust the color balance of the other colors in the rendered image to compensate for the yellowing distortion from the light source.

This crude method of compensation achieves only a very rough approximation of true color, and is highly vulnerable to large distorting effects. In particular, it can only perceive the light effects in the image sensor's narrow field of view. And it does not work at all if there is no white element in the scene.

So camera manufacturers discovered that better white balancing could be achieved by combining the image sensor's perception of white objects with the measurement output from a dedicated color sensor that has a wide field of view of approximately 180°. Successive generations of color sensors have achieved more and more accurate measurement of the CCT of ambient light, as this white paper describes below. Each improvement in color accuracy has led to an improvement in camera image quality, offering more true rendition of color across a wider range of environmental conditions.

In the most demanding cases, however, even the most sophisticated XYZ type of color sensor can be fooled into misrepresenting color. A typical such case is a scene which is dominated by a background of a single strong color. This might be, for instance, a portrait of a person standing in front a plain blue wall. The reflections from any light source will be blue-colored, and this has the effect of making any object in the scene appear more blue than it 'really' is. The resulting visual effect is a kind of distortion in which the contrast between the background color and the color of the foreground objects is rendered inaccurately.

The same effect can occur in scenes shot against a background of the blue sea or sky, or an expanse of green lawn. An RGB or XYZ sensor will capture an accurate measurement of the CCT of the ambient light, but will not be able to detect that objects in the scene itself are coloring the ambient light.

Now the latest smartphone cameras – those which achieve the highest performance scores in independent tests such as the DXOMARK benchmark – are using a yet more sophisticated type of optical sensor to separate the effect of the reflections from the background from the effect of the main light source, in order to correctly render the colors of both the background and foreground objects.

This sensor type is a multi-channel spectral sensor.

The spectral characterization of light

The human eye is a relatively crude device for visual perception. Like an RGB or XYZ sensor, the eye has three sensing elements, or 'cones', sensitive to the red, green and blue portions of the spectrum. The eye also contains rods which are fairly sensitive to relative brightness, but not in a linear fashion – for instance, when the optical power output of a typical artificial light source is reduced by 50% from maximum brightness, the human eye typically perceives the drop in brightness as just 25%.

In most conditions, the eye's three-channel method for sensing color works well enough. But in fact a source of visible light such as sunlight is a complex physical phenomenon which has a spectral power distribution over the spectrum of visible wavelengths (approximately 400nm-700nm).

A representation of the spectral power distributions of various light sources is shown in Figure 1. All of these light sources are nominally 'white light': fluorescent lamp, ultra-white LED, halogen bulb, white LED, incandescent bulb, and daytime sunlight.

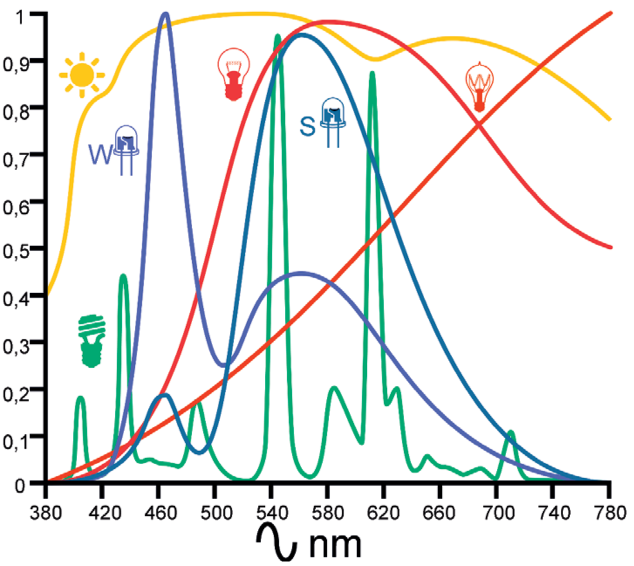


Fig. 1: the spectral power distributions of various white light sources.
(Image credit: A7N8X un-der Creative Commons 4.0 license.)

What is striking about the graph is that each light source's curve has a distinctive shape, and concentrates its radiant power in different parts of the spectrum. This explains why each source has different perceived color effects.

But now look at Figure 2, showing the spectral characteristics of the eye's sensitivity to light:

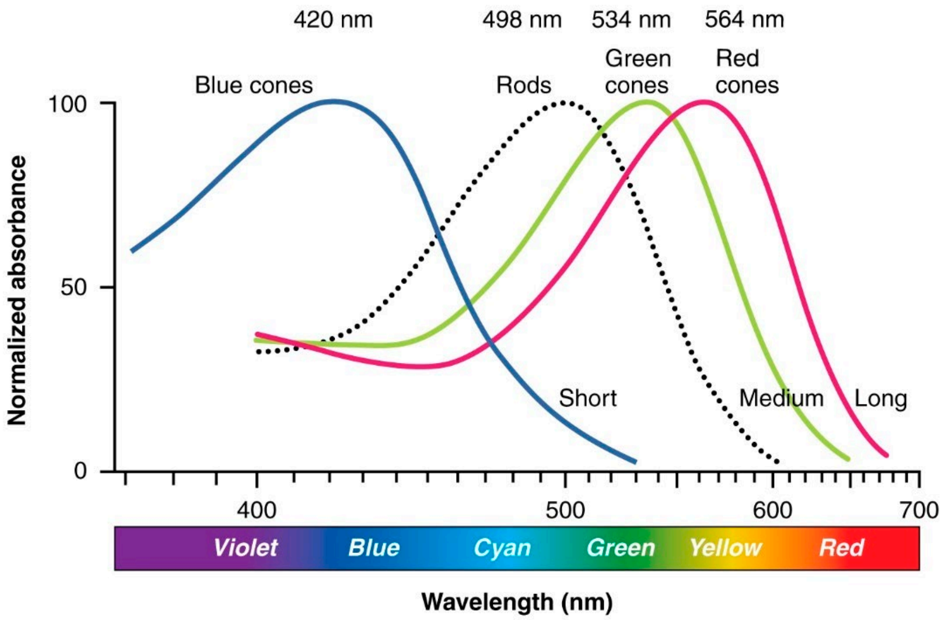


Fig. 2: average human eye sensitivity to color and brightness.

(Image credit: OpenStax College under Creative Commons 3.0 license.)

The human brain can fuse the inputs from the eye's blue, green and red cones to produce a color sense output, but it cannot distinguish the complex pattern of color peaks and troughs which distinguish a white LED from a fluorescent lamp, when both have average peak output at around 540-580nm, perceived as a blue-green white.

This is the capability enabled at chip scale by a new generation of spectral sensors developed by ams. The AS7341 spectral sensor is optimized for use in portable and mobile devices: it is supplied in a compact 3.1mm x 2mm x 1mm package suitable for mounting on a smartphone or consumer device PCB. It is an 11-channel sensor which includes eight channels distributed evenly over the visible light spectrum, as well as clear, Near Infrared and Flicker Detection channels. Because the sensor can slice the spectral power distribution of visible light into eight separate measurements, it is able to detect the distinctive spectral signature of the light sources shown in Figure 1, and of any other sources or combination of sources of visible light.

This capability is highly valuable to manufacturers of high-performance smartphone cameras. But is it useful in other applications for color sensing? To answer this question, it is helpful to understand the differences in the operation of a multi-channel spectral sensor, an XYZ sensor and an RGB sensor.

RGB color sensors

An RGB sensor commonly consists of three band-pass filters in the visible light spectrum. The peaks of the spectral graphs are not set uniformly in relation to particular wavelengths, but are defined during the design process in response to the specification of the measurement task and cost.

This kind of color measurement is not aligned to any standard or model of the human eye's perception of color. An RGB sensor can, nevertheless, be used in colorimetric tasks depending on the required accuracy. But even with the application of complex calibration methods, the accuracy of an RGB sensor's color measurement is limited by the device's three-channel configuration.

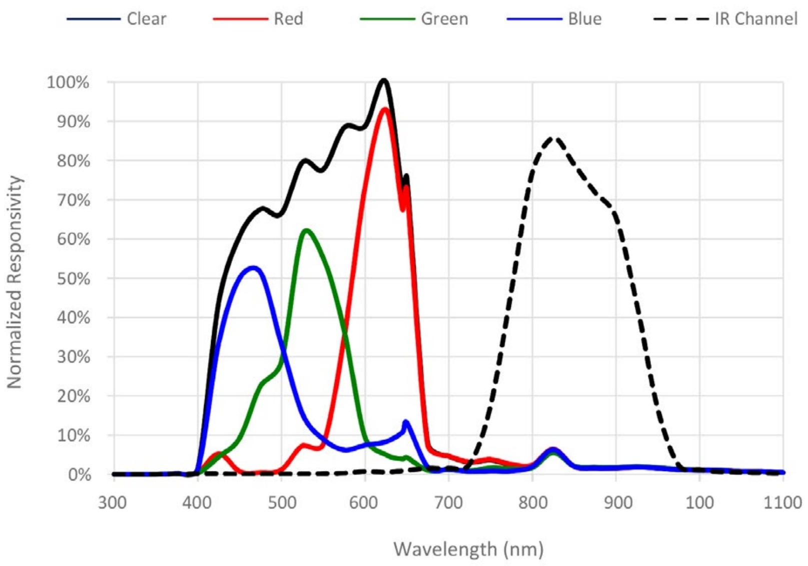


Fig. 3: typical spectral characteristics of an RGB sensor.
(Image credit: ams AG)

XYZ True Color sensors

XYZ sensors, also known as True Color sensors, may be used for absolute-value color measurements. They use interference filters, which provide a sound technological basis for the measurement of color to industry-standard definitions of color. These sensor ICs measure values as accurately as the human eye sees them. The spectral sensitivity diagram in Figure 3 reveals a close match to the human eye's sensitivity as shown in Figure 2.

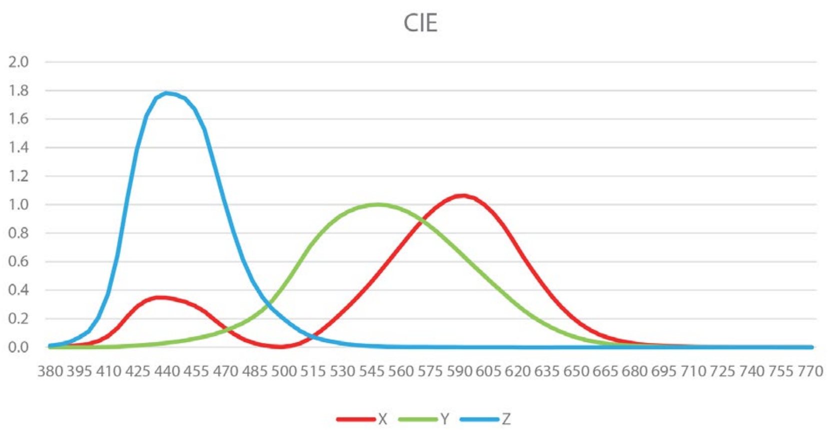


Fig. 3: typical spectral characteristics of True Color sensors, which incorporate interference filters
(Image credit: ams AG)

The interference filters allocate specific sensitivity values to each wavelength in each of three color channels. When calibrated, it is possible to render the measured color values as XYZ values (chromaticity coordinates), which are used as base values for conversion into other color spaces. XYZ coordinates are based on the CIE 1931 'Standard Observer' characteristics of the average human eye. The use of a True Color sensor IC therefore makes it possible to describe in number values the color of an object such as a swatch of fabric, or a printed block of color, in the same way as a human eye would.

Multi-channel spectral sensors

Multi-channel spectral sensors such as the AS7341 are next-generation sensors which use multiple channels to provide a high color information output at a low price point. When color coordinates are not enough, the spectral composition of objects is measured. This principle can compensate for metamerism (false color matching). A multi-spectral sensor provides the answer to the question whether an orange color sample is a mix of red and yellow, or a pure orange. Or they can measure spectral light values such as the color rendering index (CRI), as well as commonly measured values such as brightness and CCT.

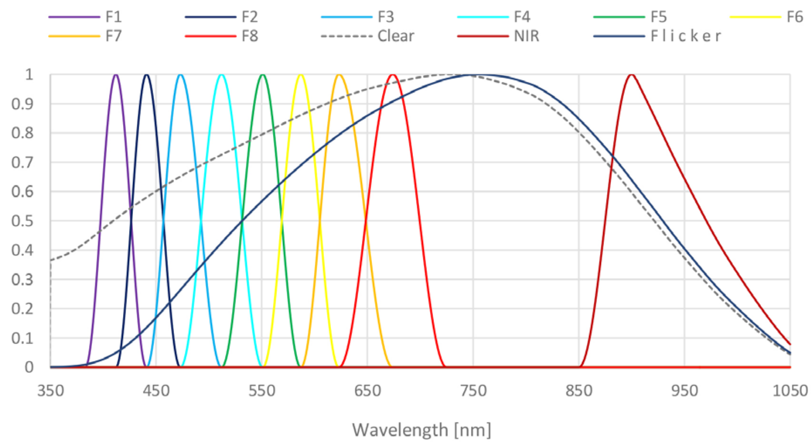


Fig. 4: the spectral sensitivity of the AS7341 multi-channel spectral sensor
(Image credit: ams AG)

Multi-spectral sensors separate the chosen spectrum into spectral channels. As Figure 4 shows, the filters are arranged in such a way that their limiting ranges align, leaving almost no gaps in the chosen spectrum.

In the visible range, a multi-spectral sensor's measurement takes place at the radiometric level rather than the colorimetric level. This means the sensor measures the spectral power distribution of the sample, and calculates the color point from these spectral values.

In the Near Infrared (NIR) range, the measured spectrum can also be used to look at specific wavelengths at which the user may identify specific substances such as moisture, fats or proteins.

The unique capabilities of the multi-channel spectral sensor

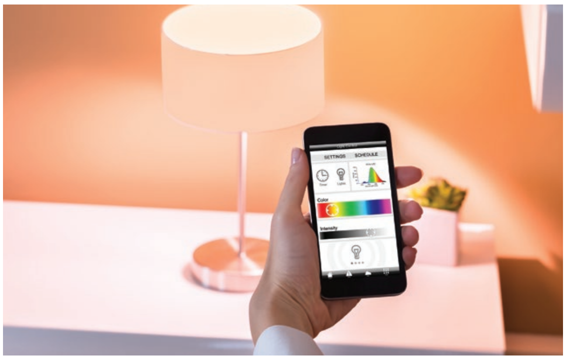
It is now possible to see why a spectral sensor such as the AS7341 is used in smartphones that have the best-performing camera according to the DXOMARK benchmark.

The shape of the spectral distribution detected by the AS7341 enables the phone's image-processing algorithms to detect the light source, such as a white LED. It can infer the light source from the shape of its spectral distribution curve even when the color point of the reflected light is not the same as the color of the light source – as happens when it is reflected from a strongly blue wall, or from a field of grass.

In scenes which have a strong uniform background color, the image processor can correctly compensate for its distorting effect, calculating from information it stores about standard light sources what the colors in the foreground would have been were it not for the distorting effect of the background.

This spectral sensing capability results in more true rendition of color even in scenes which defeat RGB or XYZ sensors.

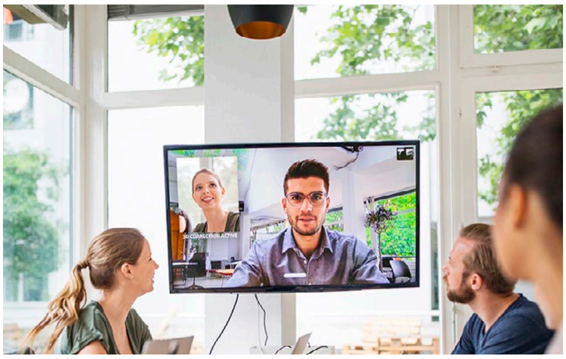
Figure 4 also shows that the AS7341 provides a flicker detection channel operating across the visible light spectrum. This enables the image processor to detect and compensate for the effect of flicker, a common phenomenon in artificial light sources powered by an AC mains electricity supply which switches at a frequency of 50Hz or 60Hz.



New consumer and commercial use cases for spectral analysis of light sources

The AS7341, a multi-channel spectral sensor supplied in a mobile device-friendly package, is used today in high-end smartphones to enable the most accurate possible white-point balancing across the widest range of lighting conditions, to produce the superior camera performance that consumers care about.

The same multi-channel measurement capabilities that mobile phone manufacturers prize, however, also have potential uses in many other types of consumer and industrial equipment.



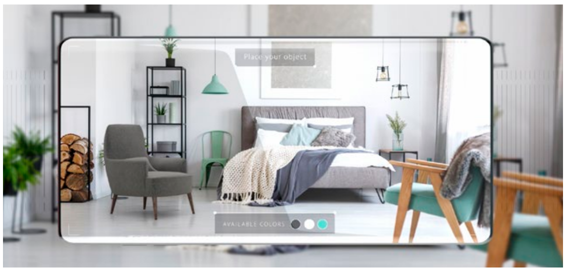
Improving picture quality in video conferencing equipment

Conventional telephone conference calling is widely used in the workplace, but almost universally disliked because of the sense of disconnection that humans feel when communicating with people who they cannot see.

Video conferencing is emerging as a preferred alternative to audio-only conference calling, but the sense of connection between participants is strongly influenced by the perceived quality of the images of the users' faces. Video conferencing systems are generally used in indoor workplaces, where the subjects will commonly be lit by harsh and flickering artificial light sources such as white LEDs or fluorescent lamps.

The use of a multi-channel spectral sensor embedded in the conference system's camera(s) enables the image-processing system to identify the light source's spectral signature, apply appropriate compensation and thus render the color of the users' skin tones, clothing, jewellery and other features faithfully. This offers scope to substantially increase the feeling of quality and realism enjoyed by participants in video conference calls.

The flicker detection channel in the AS7341 also enables banding and other flicker-induced image artefacts to be eliminated.



Environment awareness in wearable devices

Virtual Reality (VR) and Augmented Reality (AR) devices are in their infancy, but almost all manufacturers of VR/AR devices are competing to render the virtual world as realistically as possible. Accurate color rendition is a crucial visual signifier of realism. When a VR/AR device's image sensor is backed by a multi-channel spectral sensor, it can apply accurate color compensation in any lighting conditions, and with any background color, to render truly the color and brightness of real-world objects.

Environment awareness also has another use, to support healthy living regimes. Wearable devices such as fitness monitoring wristbands or smart frames (glasses) have traditionally been used to monitor body functions such as motion or heart rate. But external factors also affect health: an example is exposure to light. A multi-channel spectral sensor can identify the light sources in which the wearer spends time, and inform an app which will analyze the proportion of time spent under light sources which the user might classify as 'unhealthy', and show the time the wearer has been exposed to sunlight's dangerous parts of radiation.

Healthy lighting for homes and offices

A similar use case shows the value of embedding a multi-channel spectral sensor in indoor lighting fixtures or lighting controllers. The science of 'human-centric lighting' is a fast-developing field, and the health impacts of types of artificial light, or of specific wavelengths, are not yet proven.

Nevertheless, some users harbor concerns, for instance, about exposure to specific wavelengths of blue light in sources such as white LEDs. There is evidence that the potential for harm arises from the relative intensity of benign and harmful wavelengths, rather than the absolute intensity of a specific wavelength.

The detailed analysis this calls for is only possible with a spectral sensor – and a device such as the AS7341 is small enough to be embedded into any type of lighting fixture.

In tunable white lighting fixtures, the spectral information provided by the AS7341 also allows for the dynamic configuration of light output in combination with ambient light to provide a user-specified spectral power distribution.

Interference-immune security cameras and CCTV

An important function of security cameras and CCTV systems is to identify people by rendering a sufficiently detailed and clean image of their face. This can be important, for instance, in criminal investigations, or in the search for missing people.

These systems often work in conditions which compromise the performance of cameras, such as under low-CRI floodlighting. In addition, criminals have learned that, by directing high-frequency strobe-effect lighting at security cameras, they can so impair the image quality that the cameras are rendered practically useless.

Embedding an AS7341 multi-channel spectral sensor in security cameras and CCTV systems provides a solution to both these challenges. It enables the true rendition of color and contrast under harsh lighting conditions. The high-performance image processing and color compensation supported by the AS7341's spectral measurements helps produce high-contrast, accurate renditions of people's faces even from relatively low-resolution image sensors.

The flicker detection channel in an AS7341 also combats attempts to use strobe lighting to interfere with a camera's operation. When high-frequency strobe effects or flicker are detected, the AS7341's output can be used to synchronize image capture with the dark intervals between strobe emissions. During these dark intervals, normal camera operation can be maintained, with accurate color compensation supported by the multi-channel measurement outputs in the visible light spectrum provided by the AS7341.

Conclusion

Accurate rendition of color in imaging and lighting systems has long been a characteristic valued by consumers and professional buyers. New developments in color sensing have seen the introduction of a new generation of multi-channel spectral sensors which for the first time provide for chip-scale spectral analysis of incident light – a more detailed type of information than the color-point measurements provided by the XYZ color sensors pioneered by ams.

A device such as the ams AS7341 spectral sensor provides accurate color measurements backed by reliable detection of the signature of any kind of visible light source, in almost any ambient light conditions.

Now providing light-source information in world-leading smartphone camera systems, the AS7341 is also finding uses outside the smartphone, offering unique value in use cases in lighting fixtures, specialist camera systems and wearable devices.

Biography

Kevin Jensen, Senior Marketing Manager at ams, is a sensor and lighting expert. He is a bilingual German-American dual citizen with international experience in management, sensors, electronic engineering, expansion strategies, internationalization and marketing. His background is in spectral analysis, optical sensors, signal analysis, system solutions and software concepts. He graduated with a General Management Masters and a Bachelor background in Engineering and Software Development.

For further information

ams AG Headquarters
Tobelbader Strasse 30
8141 Premstaetten · Austria
Phone +43 3136 500-0
sensors@ams.com
ams.com