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SURFACE COLOURS USED AS VISUAL SIGNALS ON ATON

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1. INTRODUCTION

This document is intended for the provision of guidance to the technical aspects of selecting surface colours as defined in Recommendation *R0108 Surface Colours Used as Visual Signals on Marine Aids to Navigation* 0. It includes specification of colours, measurement, weathering and colour collections.

A surface colour is a colour perceived to belong to a surface. The colour of an ordinary surface, such as an ordinary paint or an opaque plastic material, is the most common kind of surface colour and is known as an ordinary colour. Other kinds of colours include fluorescent (or luminescent) colours, transilluminated colours (for example, the colours of internally illuminated panels) and the colours of retro-reflecting materials.

A surface colour can be specified in terms of its chromaticity and its luminance factor. Chromaticity co-ordinates, which may be plotted on a chromaticity diagram, define the chromaticity and the luminance factor is a measure of the lightness of the colour relative to a pure white diffusing surface under the same illumination. As a specification must be made with respect to some type of illumination, the International Commission on Illumination (CIE) has precisely defined several standard illuminants. The results of the measurement of a colour can depend significantly on the degree of gloss on the surface, and the CIE has also recommended various geometries of illumination and measurement.

Two colours may be measured as having the same chromaticity and luminance factor under one illuminant, but dissimilar ones under a different illuminant. This phenomenon is known as metamerism and its effect can be very significant. It is advisable to check that the appearance of a signal colour will remain reasonably constant under the various types of illumination by which the colour is expected to be seen.

A surface colour is usually seen in relation to other surface colours, and the perception of the colour can be quite markedly influenced by the presence of the other colours. Hence, a signal colour should always be checked, especially at a distance, for its appearance among the surrounding colours.

Deterioration of surface colours in use is a common occurrence and care must be taken that signal colours always remain in compliance with their specifications. Particular attention should be given to fluorescent colours, as they are liable to undergo rapid changes of chromaticity and luminance factor on exposure to radiation and wear if they are not provided with special protective surfaces. Frequent inspections of fluorescent colours are advised until the normal useful life has been confidently ascertained for each typical situation where these colours are used. Special care may be needed if fluorescent and non-fluorescent colours of the same chromaticity are chosen to be used together, as different deteriorations might produce dissimilarities of the chromaticity.

2. SPECIFICATION AND MEASUREMENT OF THE COLOURS

The guidance in this document is based largely on established experimental work involving the recognition and naming of colours but has also taken into account common practice and the limitations of materials. The method of specifying colours conforms to the recommendations of the CIE. The recommended limits of the chromaticity of colour are specified by means of limiting boundaries that enclose a chromaticity region on a CIE standard chromaticity diagram and can be found in IALA Recommendation *R0108 Surface Colours Used as Visual Signals on Marine Aids to Navigation (E-108)* 0.

The luminance factor ß and the chromaticity co-ordinates x, y strongly depend on the measurement principle and the structure of the surface, texture, gloss, patterns etc. To make colour measurement precise and repeatable various specifications are necessary. It is stated that the chromaticity regions and the limits of the luminance factor are only valid when the following specifications are fulfilled.

2.1. STANDARD ILLUMINANT

The standard illuminant specified for the measurement of colour is D65, which represents a typical phase of daylight and has a correlated colour temperature of approximately 6500 Kelvin. It is a tabulation of values across and beyond the visible spectrum and does not exist as a real light source although fairly close approximations to it can be realized.

2.2. MEASUREMENT GEOMETRY

To take the effects of the coloured surface into account a 45º annular/normal geometry (45/0) is used for measurements. The report *CIE No. 15* (point 5.1.2) 0 emphasises this geometry as well. Measurement with a geometry of normal / 45º will usually produce an identical result.

2.3. STANDARD OBSERVER

The 2° standard observer (*CIE No. 15*, point 6.1 0) is used for large observation distances and above all to consider the attitudes of the human eye; this is the area with the highest cone density and is therefore relevant for colour perception. The 2° observer covers the application for Marine Aids to Navigation (AtoN) purposes.

2.4. GLOSSINESS OF THE SURFACE

A glossy surface produces a saturated colour, whereas a matt-finished surface has only a poor saturation even when both surfaces are based on the same colour pigment.

As a result, the recommended IALA chromaticity regions can only be achieved by a surface with enough glossiness. Therefore, it is recommended to use glossy colours for AtoN.

2.5. FLUORESCENCE

Fluorescence is the process by which electromagnetic radiation of one wavelength is absorbed and re-radiated at another wavelength. Sometimes a fluorescent material will absorb non-visible light and emit it as visible light. Fluorescence and ordinary reflectance of radiation take place simultaneously and at the same wavelengths. When the colour of a fluorescent sample is measured, the fluoresced light is added to the reflected light at those wavelengths. Therefore, reflectance can exceed 100%. The UV contribution from the reference light of the measurement instrument is often not included and can vary from instrument to instrument. However, instruments that use a Xenon light source as the reference light can give an approximation of UV daylight.

The common methods of colour measurement of fluorescent material in laboratory are polychromatic light irradiation method and monochromatic light excitation method. The characteristic of the polychromatic light irradiation method is that the polychromatic light simulating D65 is directly used. The spectral radiance factor of the fluorescent material under the illuminant is directly measured and then the tristimulus value is calculated. The limitation of this method is that the result is only based on this particular illuminant and could not predict the colour characteristics of the fluorescent material under another illuminant. However, the monochromatic light excitation method does not have this limitation and it can measure the colour characteristics of the fluorescent material under each illuminant with specific wavelength.

Due to certain UV components in the illuminant during the colour measurement of the fluorescent material, attention shall be paid to the calibration and the reference materials are also different from that of ordinary colours.

The chromaticity region recommended for each fluorescent colour is identical to the region of the corresponding ordinary colour. The colour of a fluorescent material should be measured with any protective surface that is normally used with the material.

2.6. ADDITIONAL CONSIDERATIONS

The boundary lines of a chromaticity region, and the restrictions that may apply to the appropriate luminance factor, can together be referred to as the colour limits of a colour. The recommended colour limits are extreme values that should not be transgressed (except as mentioned in sections 5.1, 5.4, 5.5 and 5.6). More restrictive limits may be defined as appropriate to particular requirements and they may be desirable for the signal colours used within one signalling system if substantial differences in appearance, either of chromaticity or luminance factor, are to be avoided. Also, the recommended colour limits of a colour are intended to apply throughout its entire service life, so examination of its condition may be required from time to time.

It should be noted that, with the exception of the purple boundary of red, the specifications have not been designed to assist people with severely defective colour vision, most of whom will have great difficulty distinguishing between red and green.

3. MEASUREMENT DEVICES

The measurement device consists of two main components. One is the light source, which illuminates the colour sample and the other is the light receptor. Although it is possible to build up these components on an optical bench, for practical measurements all-in-one devices with the light source, the receptor and a microprocessor to calculate the colour coordinates are offered.

3.1. LIGHT SOURCE

3.1.1. GEOMETRY

The light source, the sample and the receptor have to be arranged in a specific geometry called 45/0 or 0/45. Only a small flat part of the sample will be measured. This part will be masked with a circular screen.

The measuring field will be illuminated with light incident under an angle of 45° towards the vertical line. This can be done with a ring illumination (annular), an array of several light sources (circumferential) or at least two lights on both sides of the vertical line (single-plane).

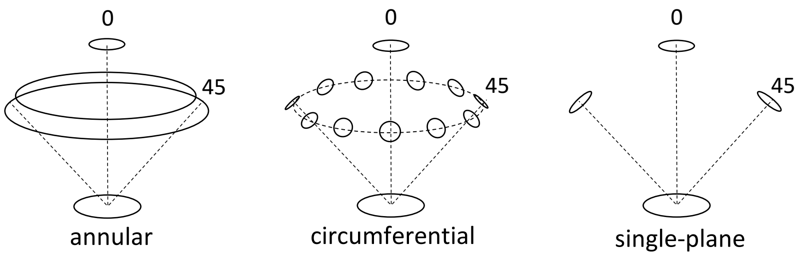


Figure 1 45° Illumination / 0° Measurement

With 45/0 (0/45) annular, circumferential or single-plane geometry, the measurement results may be different, which is also related to the surface properties of the sample. Therefore, the comparison of surface colour measurement results shall be based on the same measurement geometry. If 45/0(0/45) single plane geometry is adopted, the measured result shall be produced according to the average value of rotation measurement result, four times or more rotation measurement is undertaken until there is no obvious difference between the two adjacent measurements. Then the average value is taken as the final result. It is not recommended to use the single-plane geometry for on-site measurement but annular or circumferential geometry is recommended.

3.1.2. SPECTRUM

The spectrum of the light source should have a continuous and stable spectrum of at least 400 nm - 700 nm for ordinary colours or retroreflective sheets of day-time conditions. For better results, an interval from 380 nm to 780 nm is recommended.

Special care should be taken for fluorescent colours, which definitely need excitation with wavelength up to 380 nm. The fluorescence depends strongly from the UV and blue light and small changes at these wavelengths may change the colour significantly. Many manufacturers provide filtered xenon lamp illumination which can simulate sunlight even at blue and UV.

For even more accuracy, the monochromator excitation method should be used.

3.2. MEASUREMENT INSTRUMENTS

The measurement is usually done with a spectrophotometer. For minor accuracy, colorimeters may be used which are simpler and cheaper.

3.2.1. SPECTROPHOTOMETRY – ABSOLUTE MEASUREMENTS

A spectrophotometer measures the amount of light energy reflected from an object at several intervals along the visible spectrum. It consists of four main parts; the light source (an approximation of the standard illuminant, usually a xenon light source), the sample (the surface colour), the detector and the output (a display or connected to a PC via software), as shown in Figure 2. The spectral data are shown as a spectral reflectance curve and can be weighted with a standard illuminant and standard observer.

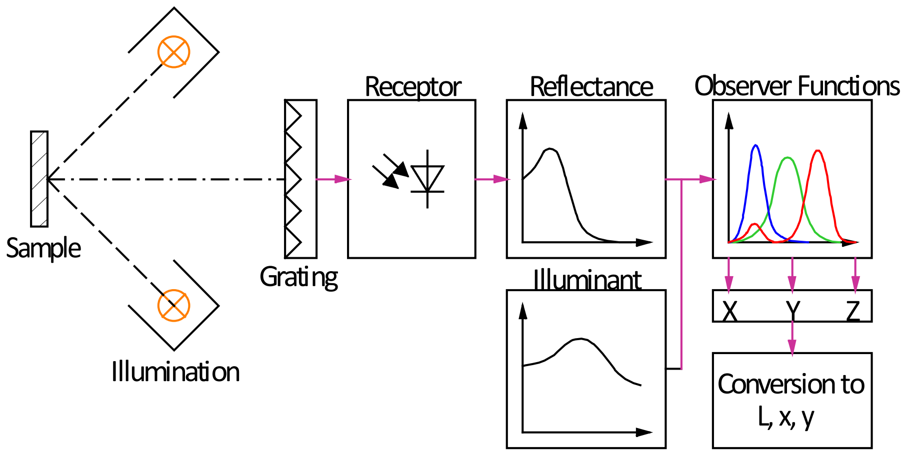


Figure 2 Component Parts of a Spectrophotometer

3.2.1.1. 3.2.1.1 Charge Coupled Device (CCD) Spectrophotometer

A CCD is a type of image sensor that detects light. It is an integrated circuit made up of an array of linked/coupled light-sensitive receptors. The light-sensitive receptors detect the intensity of light received and convert it into an electrical signal. The CCD detector corresponds to the range of wavelengths on a spectrophotometer. Each pixel on the CCD represents a specific wavelength of light, and the more photons absorbed, the more electrical signal generated. Therefore, the electrical signal output by the CCD at each pixel is proportional to the light intensity at each corresponding wavelength. The resultant output is a reflectance curve, which can then be weighted against an illuminant and observer. Further conversions to alternative units can then be performed.

This type of instrument is often used for in-situ (outdoor) measurements. However, there are some limitations in wavelength accuracy (<10 nm).

A description of the measurement procedure for laboratory measurements can be found in annex B and for on-site measurements in annex C.

3.2.1.2. 3.2.1.2 Scanning Monochromator

A scanning monochromator uses a diffraction grating that "steps" through the visual spectrum to separate the individual wavelengths (1-5 nm). These instruments are generally quite large and heavy and are more suited to laboratory measurements due to the time it takes to perform the measurement. However, they are very accurate (~1 nm).

A description of the measurement principles and derivation of the data can be found in annex D.

3.2.2. COLORIMETRY - RELATIVE MEASUREMENT

Colorimeters are tristimulus (three-filtered) devices that make use of red, green and blue filters to emulate the response of the human eye to light and colour as shown in Figure 3. Due to filter imperfections and not recording the spectral reflectance of the sample, tristimulus colorimeters are not suitable for assessing IALA's surface colour requirements.

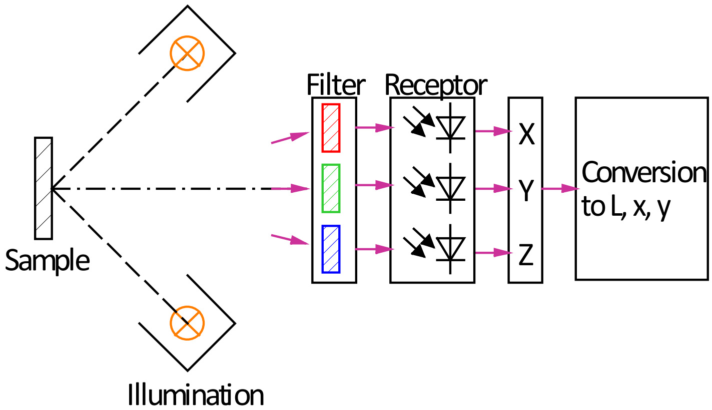


Figure 3 Component Parts of a Colorimeter

However, colorimeters used as colour difference meters do provide reasonable results.

A description on the limitation of this method can be found in annex E.

4. MEASUREMENT METHODS AND TECHNIQUE

Due to material selection, quality control and maintenance of visual AtoN, different measurement environments require different measurement accuracy. On the basis of different measurement environments, measurement methods can be divided into laboratory measurement and on-site measurement. Compared with on-site measurement, laboratory measurement has higher requirements on measurement conditions and measurement instruments, and sample preparation and selection will be different.

4.1. SELECTION OF SAMPLING POINTS

For the submitted samples or AtoN to be measured, 3 to 5 testing points shall be selected for each colour and be scattered. For on-site measurement, the points shall also be selected in the direction of the sailing observation.

4.2. LABORATORY MEASUREMENT

1 Environmental Conditions

Temperature: 25 °C ± 5 °C

Humidity : relative humidity ≤(85 ± 5%), no condensation.

The working environment of the instrument shall be free from direct light, corrosive gas, strong vibration or strong electromagnetic interference indoors.

2 Measurement Samples

The measurement samples shall be made of similar substrates and the same coatings as the measurement visual AtoN.

3 Instrument Requirements

In addition to meeting the CIE 45°/0° (0°/45°) geometry, the measurement instrument shall also meet the following requirements:

a Light Source - Select the stable light source with continuous spectrum in 380 nm ~ 780 nm for the measurement of ordinary surface colours and the surface colours of retro-reflecting materials of day-time conditions. For fluorescent materials, use the polychromatic light simulating the standard illuminant D65 (the category is evaluated according to CIE 51.2 and shall not be lower than category BC) if polychromatic light irradiation method is selected. The tunable monochromatic light source in 250 nm ~ 800 nm can also be used if monochromatic light excitation method is selected.

b Spectrum Measurement - The required wavelength range is 400 nm ~ 700 nm. For higher accuracy a range 380 nm ~ 780 nm is recommended. The spectral resolution is not greater than 3 nm. The wavelength accuracy is better than ±1nm. The reporting interval is ≤ 10 nm.

c Sampling Aperture - It is recommended that the ratio of instrument's sampling aperture to the radius of the sample is less than 0.04 m, and the measurement surface shall be filled with the entire sampling aperture.

d Equipped with standard white standard plate and zero calibration device for instrument calibration.

4 White Standard Plate

Use spectral reflectance data of 380 nm ~ 780 nm of the white standard plate under CIE45/0 or 0/45 geometry for calibration for the measurement of ordinary colours and retro-reflecting materials of day-time conditions.

Use spectral radiance data or chroma data under CIE45/0 or 0/45 or CIE BC grade D65 illumination conditions, which is similar to the measured samples for the measurement of fluorescent materials using polychromatic light irradiation method.

A description of the measurement procedure can be found in annex B.

4.3. ON-SITE-MEASUREMENT

1 Environmental Conditions

The surface of the measurement AtoN shall be clean and dry.

There shall be no corrosive gas or strong electromagnetic interference in the surrounding environment.

2 Measurement Instrument

It is recommended to use integrated measurement instruments that can be self-calibrated for on-site measurement. It is also recommended to adopt the 45/0(0/45) annular or circumferential illuminance /observation geometry, and the following requirements shall be met:

a Light Source - Select the stable light source with continuous spectrum in 380 nm ~ 780 nm for the measurement of ordinary colours and the colours of retro-reflecting materials of day-time conditions. Use the light source with continuous spectrum in 380 nm ~ 780 nm for the fluorescent materials with the adjustment of its UV component.

b Spectral Measurement - The wavelength range is at least 400 nm ~ 700 nm. The spectrum resolution is not greater than 10 nm. The wavelength accuracy is better than ±2 nm. The reporting interval is ≤ 10 nm.

c Sampling Aperture - It is recommended that the ratio of instrument’s sampling aperture to the radius of the sample is less than 0.04 m, and the tested surface shall be filled with the entire sampling aperture.

d Equipped with a white standard plate and a zero calibration device.

3 White Standard Plate

Use spectral reflectance data of 380 nm ~ 780 nm of the white standard plate under CIE45°/0°(0°/45°) geometry for calibration for the measurement of ordinary colours and retro-reflecting materials of day-time conditions.

Use the fluorescent standard plate for the measurement of fluorescent materials, in addition to using the same white standard plate for the measurement of ordinary colours and retro-reflecting materials.

A description of the measurement procedure can be found in annex C.

5. CONSIDERATIONS OF PARTICULAR COLOURS

5.1. RED

A minimum value of 0.07 is specified in *R0108* Table 1 0for the luminance factor of ordinary red, but significantly higher values can usually be realized and, in most circumstances, a value greater than 0.10 should be maintained.

The chromaticity region of red, which is identical for both ordinary and fluorescent colours, has been defined on the basis of achieving a very high probability of correct recognition for the colour, and it should prove to be quite practicable for ordinary reds with glossy surfaces and for fluorescent reds. There is doubt though, if their surfaces are matt or even semi-matt, whether serviceable materials of various kinds can always be manufactured in compliance with the restriction imposed by the white boundary of the chromaticity region for ordinary red. Also, it is not yet certain that serviceable materials, with glossy surfaces when new, can necessarily be manufactured so that their compliance continues throughout a reasonable service life if considerable loss of gloss occurs. Therefore, it is proposed that the chromaticity region for ordinary Red may be extended, but only for materials with matt or semi-matt surfaces, to a revised white boundary of y=0.840 – x. This provision for ordinary red colours should not be used unless it is necessary and then only with the understanding that the probability of correct recognition of the colour will be significantly reduced. The problem discussed here is not expected to arise with any of the other chromatic colours.

5.2. ORANGE

The probability of correct recognition of orange is usually not as high as that of red or yellow; moreover, when these colours subtend very small visual angles, orange and red, or orange and yellow, are very likely to be confused. Hence, in considering signal colours that need to be recognized at a distance, orange does not provide a satisfactory additional colour to a system that includes red and yellow. If orange is completely excluded from a system of signal colours for AtoN, the adjacent hue boundaries of red and yellow should remain as recommended in the Tables, since, otherwise, correct identification may not be made even at close ranges and the colours will not exhibit a reasonably consistent appearance world-wide.

Nevertheless, orange is probably the best ordinary colour for conspicuity against the sea, and it should preferably be reserved for those objects for which detection in the water is more important than recognition of their colours. The objects that require this consideration are items of emergency equipment, such as life jackets and life rafts. The highest conspicuity will be obtained with fluorescent colours, and then fluorescent red-orange may be used and may, in some situations, be more conspicuous than fluorescent orange, but fluorescent red-orange is not likely to be seen as distinct from fluorescent red.

5.3. YELLOW AND WHITE

Discrimination between yellow and white is not practicable when they subtend very small visual angles, so they should not be considered as separate colours except for close viewing. In particular, it would be inadvisable to create any circumstances that required unequivocal distinction between yellow and white in retroreflecting materials, whether by day or by night.

There is a low probability of recognizing, or even detecting, white on its own at sea.

5.4. GREEN

As an ordinary colour, green does not usually show well at sea. However, colours of fluorescent green can be obtained with exceptionally high purities, and they will be very much more recognizable in most conditions.

It may be desirable, if green is required as a background colour on a sign with symbols or alphanumeric characters, to use a special dark colour. For example, one having a value of luminance factor lower than the minimum value recommended in *R0108* Table 1 0. There is a possibility of confusing green with blue at the blue boundary of the green colour. To avoid this, IALA has introduced an IALA preferred green zone. This is shown on the chromaticity regions graph and associated tables in *R0108* 0.

5.5. BLUE

On inland waterways, and in estuaries and harbours, where colours may be seen at close range, blue may prove to be a useful signal colour; but, at a distance, particularly at sea, it is unlikely to be easily recognized.

Although the recommended value of minimum luminance factor in *R0108* Table 1 0 is 0.07, values significantly higher are attainable, and they should be required whenever possible if blue is to be seen alone.

It may be desirable, if blue is required as a background colour on signs with symbols or alphanumeric characters, to use a special dark colour, that is, one having a value of luminance factor lower than the minimum value recommended in *R0108* Table 1 0. In such circumstances, a value as low as 0.05 may be considered for this special dark blue, which should anyway have a chromaticity conforming with the specification for ordinary blue, and which should never be used alone anywhere as signal colour.

5.6. BLACK

A maximum value of 0.03, as specified in *R0108* Table 1 0, is recommended for the luminance factor of ordinary black if surfaces are glossy, but, if surfaces are matt or semi-matt, then it may be necessary to allow a maximum value of 0.04 although the probability of correct recognition will thereby be lowered.

6. PERSISTENCE OF COLOUR APPEARANCE

During operational use, the coloured surface of a Marine AtoN is affected by several factors which can have more or less influence on the visual performance.

6.1. DIRT COVERING THE SURFACE

Marine fouling and bird lime are well-known dirt covering issues on buoys, but salt deposits from sea water and industrial air bourn pollutions can also have impacts on the visual performance of the AtoN to the point of causing the risk of misidentification by the mariner.

Use of anti-fouling paint or anti-fouling chemical compound if possible and regular use of high pressure cleaners are recommended.

6.2. MECHANICAL ABRASION

Mechanical abrasion occurs often on painted buoys when vessels pass too close to the AtoN and make scratches and dents in the surface. It could also occur over the AtoN expected lifetime due to sand or other solid airborne particles such as cement.

The surface of plastic buoys are more resilient against mechanical abrasions due to the fact that the material of the buoy is dyed by the same colour as the surface.

6.3. MECHANICAL STRESS

Mechanical stress as a cause of colour fading is mainly seen in plastic buoys. This is due to a loss of ductility exhibiting as whitening of the surface, resulting in colour fading.

On steel buoys, these changes in the surface are not seen but the difference in the coefficient of expansions between steel and the painted cover of the surface can result in cracks in the surface which affect fading and degradation of the surface colour.

6.4. PIGMENT DEGRADATION

Degradation of plastics due to ultraviolet (UV) light is inevitable and must be considered even from the manufacturing process. The type of plastic material selected and the addition of UV inhibitors and stabilizers used to protect the plastic will impact the design life of the coloured surface.

Degradation of plastic strength and loss of ductility is accelerated in latitudes with greater exposure to UV energy.

This process could be slowed down if the appropriate combination of inhibitors and stabilizers is used to guarantee the surface colour stability required for the lifetime expectancy of the plastic material selected, also considering the operational environment.

Degeneration of the painted surface colours of steel buoys depends significantly on the strength and quality of the paint.

Rapid pigment degradation is observed on AtoN painted with fluorescent colours. The speed of degradation can be reduced by a final coat of clear UV varnish applied to the coloured surface.

7. COLOURED ATONS IN PRACTICE

It should also be recognized that as soon as a coloured surface is exposed to the atmosphere, the colour will begin to change. This is due to the degradation of pigments and dyes in sunlight, the breakdown of the glossy surface film and the production of light coloured particles due to the breakdown of the coloured surface. Bright colours (particularly fluorescent colours) break down most rapidly, while darker colours last the longest.

Coloured surfaces on buoys and other structures close to the water are also subject to salt deposits, marine growth, bird fouling, etc. Effective colour retention will depend on regular maintenance cleaning which will be simplified by utilising paint with a hard and high gloss surface.

It is important to remember that signal colours should be clearly recognizable in the conditions in which the mariner will view them. The perception of a colour will vary depending on the ambient lighting conditions, the background colour against which the colour is viewed and the surface finish of the colour (the gloss in the case of a paint finish).

They should contrast sufficiently with the local background and watercolour for them to be easily recognised. Dark green colour should be used on buoys on inland waterways where they are viewed against a predominantly light green background. For example, in Nordic countries, light colours are more easily visible in twilight and also against background luminance.

In recent years, health and safety regulations have prohibited the use of many traditional pigments and alternatives may not have the long-term stability of those used in the past.

8. MONITORING COLOUR STATUS DURING SERVICE

As described in Section 5, the colour of the surface will change over time. It is important to monitor the status of the colour to ensure it is in compliance with IALA Recommendation *R0108 Surface Colurs Used as Visual Signals on Marine Aids to Navgation* 0.

The colour may not degrade consistently across the surface so it is necessary to have a representative number of measurement points compared of the surface area.

A measurement should be taken at least every 1 m^2, and the average x, y, Y coordinates are then calculated. The average of the readings should be used to compare the results to the *CIE 1931 Standard Colorimetric System* 0with the IALA coordinates as outlined in *R0108* 0.

Areas of obvious colour non-compliance, e.g. where marine growth obscures the colour, should be avoided when recording values for use in the average colour value assessment. For evaluation, fading of the colour surface measurement points which are obvious not in compliance with the colour e.g., close to the waterline where marine growth is on the coloured surface. This part should be avoided when calculating the average value of the colour for assessment of the specific colour.

However, for evaluation of the general performance of a day mark or visual part of a buoy structure, the surface of the entire surface should be included in measurements, including measurement points where the colours are obviously not in compliance with the specified colour.

Figure 4 Coloured part with marine growth should be avoided when evaluating the fading of the colour but included when evaluating the visual day mark colour of the AtoN.

Instrumentation for measurement is outlined in section 3.0. Consideration of which type of instrument used will depend on the environment where the measurements are carried out. For practical field use, a robust handheld instrument is recommended. Available instruments commonly have a wide range of functions e.g., to record average values, acceptance criteria etc.

Visual comparisons using a colour swatch is acceptable if a measurement device is not available or impractical to use. The use of swatches should not be used for higher accurate compliance testing. An example of a swatch test kit is shown in annex A.

Below are examples of measurement methodology for different types of AtoNs:

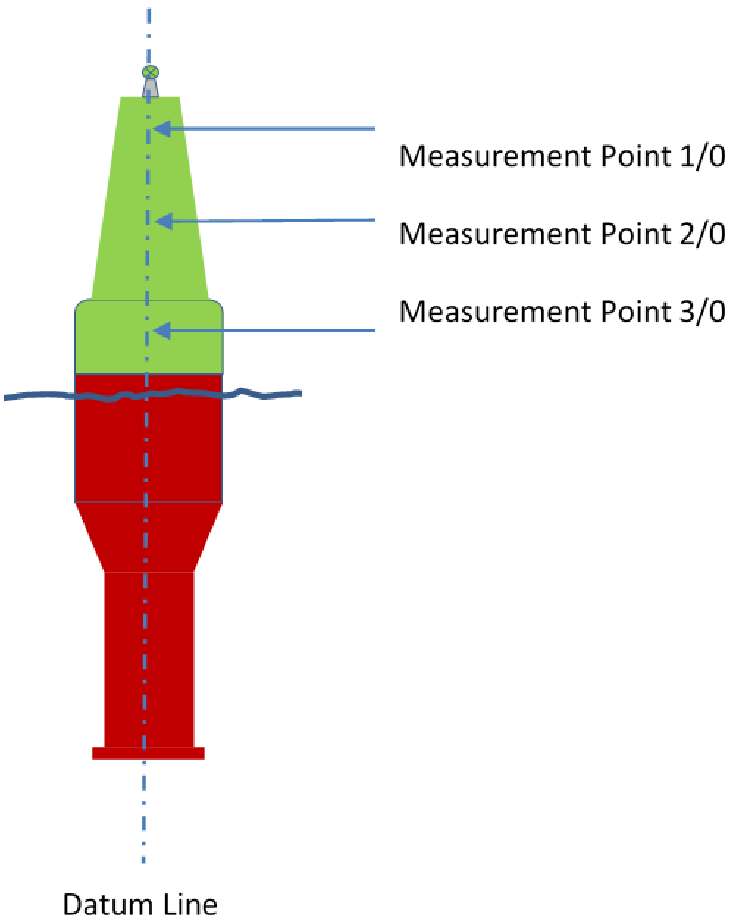


Figure 5 Vertical Measurement Points and Datum Line

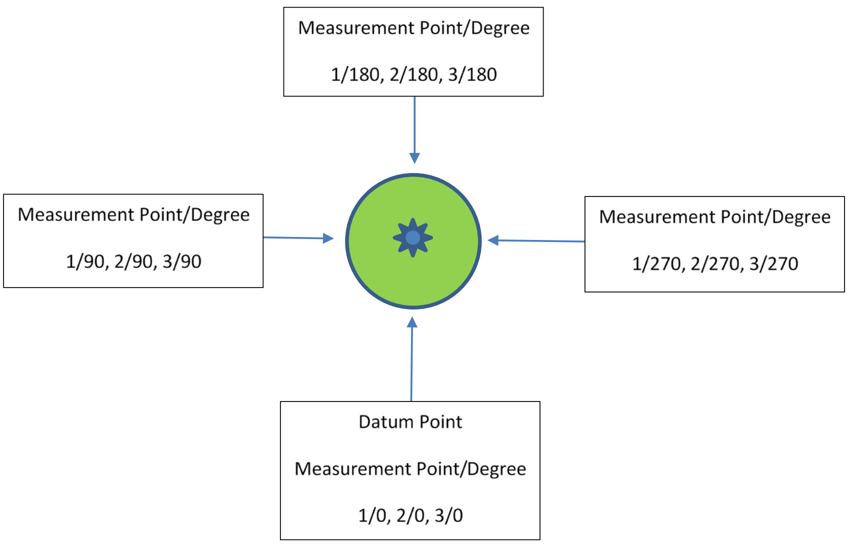


Figure 6 Top view of buoy with Datum Point and Measurement Points

Figure 7 An example to use ID number of the buoy as a reference point (Datum)

Table 1 Matrix for registration and calculation of average values of Y, x and y of a buoy

Measure Point/Degree	**Y**	**x**	**y**
1/0			
2/0			
3/0			
1/90			
2/90			
3/90			
1/180			
2/180			
3/180			
1/270			
2/270			
3/270			
Average values			

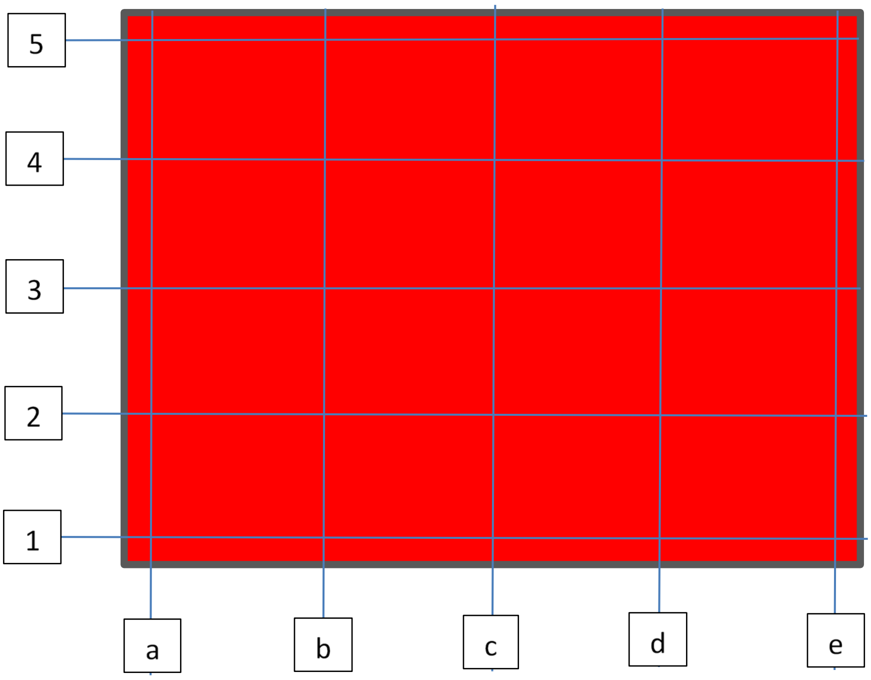


Figure 8 Day Board with measurement points

Table 2 Matrix for registration and calculation of average values of Y, x and y of a day board

Measure Point	**Y**	**x**	**y**
a1			
a2			
a3			
a4			
a5			
b1			
b2			
b3			
b4			
b5			
c1			
c2			
c3			
c4			
c5			
d1			
d2			
d3			
d4			
d5			
e1			
e2			
e3			
e4			
e5			
Average values			

9. WEATHERING TEST

The durability of the surface of Marine Aids to Navigation is important for functional performance and for the operational cost in general.

A buoy during its operational lifetime is affected by different influencing factors such as temperature change, moisture, radiation, corrosive salts, oxygen, air pollution, biological substances (guano), mechanical stress etc.

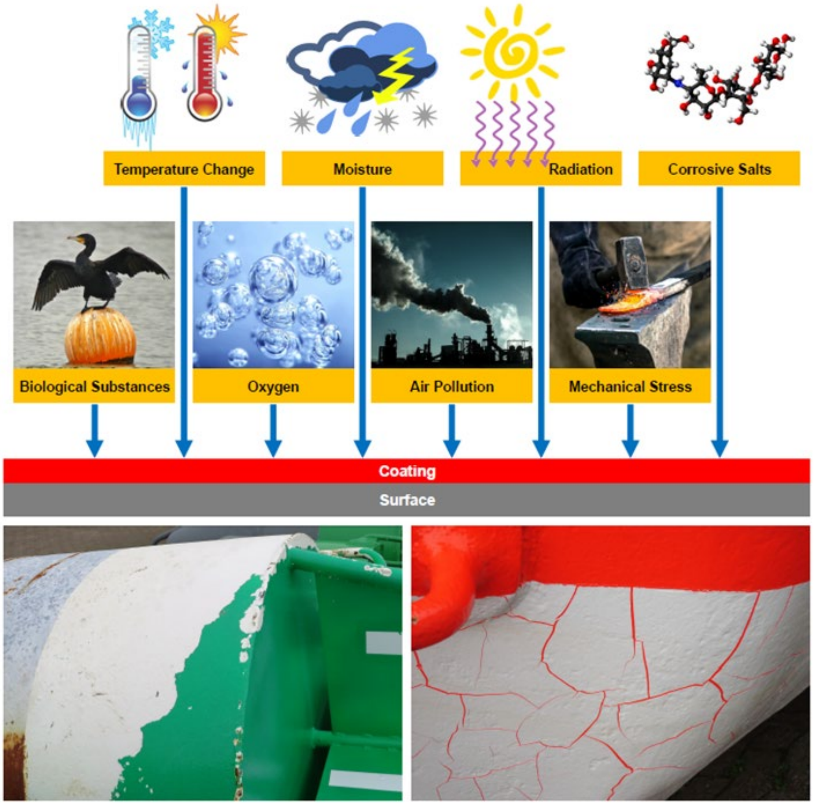


Figure 9 Influencing factors

To avoid rapid degradation of the colour of a painted buoy or the surface of a plastic buoy, it is important to verify the durability of the surface coating and colour before deployment.

In practice, there are three different methods to evaluate how fast a surface colour degrades:

- In situ weathering
- Outdoor weathering test field
- Artificial weathering in laboratory

Changes in chromaticity coordinates, luminance factors, glossiness and coating thickness can be determined by measurement and analysis.

9.1. IN SITU WEATHERING

In situ weathering is the most comprehensive way to conduct trials on AtoN due to fact that the test object is situated exactly in the specific environment the object is intended to be used in. The actual environment represents all influencing factors and the trial provides a complete test of the durability and robustness of the tested object at the specific location. Influencing factors varying considerably from location to location and accordingly, observations differ from one location to another.

In situ testing is time-consuming and a lengthy procedure and access to the test area e.g. at open sea can be difficult and expensive to reach.

Guidance on monitoring colour status during service is given in section 8.0 of this document.

Figure 10   In-situ testing

9.2. OUTDOOR WEATHERING TEST FIELD

Outdoor weathering tests are conducted on shore-based test fields where material or specimens of the material are arranged on specially designed racks. In this arrangement, specimens are exposed to direct sunlight and other influencing elements but the influencing elements are only as they are at the actual test field rather than at the specific AtoN location.

At an outdoor weathering test station, influencing factors are comparable for all simultaneously weathered samples.

Outdoor weathering tests are easier to conduct compared to in-situ tests but the duration of the test takes as long as an in-situ test.

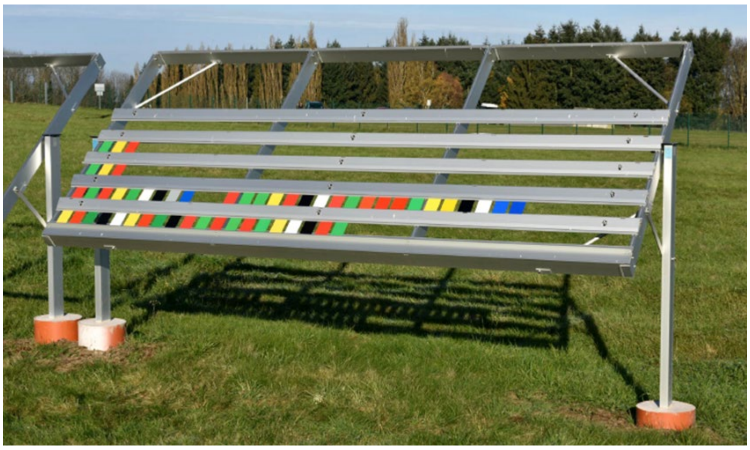


Figure 11   Outdoor weathering test field

9.3. ARTIFICIAL WEATHERING IN LABORATORY

9.3.1. METHOD

A laboratory artificial weathering test is an indoor test where the influencing elements can be controlled and modified for an accurate test specification. The results are comparable for all measurements carried out in this way.

The most common and important influencing factors considered during artificial weathering test are radiation, moisture and heat. Air pollution, chemical processes, salt, bird fouling etc. are not considered.

An accelerated weathering chamber reproduces the damage caused by sunlight, rain and dew. In a few days or weeks, the chamber can reproduce the damage that occurs over months or years outdoors. To simulate outdoor weathering, the chamber exposes materials to alternating cycles of simulated sunlight or UV light and moisture at controlled, elevated temperatures.

For artificial weathering tests, two different methods are standardized and therefore world-wide accepted.

- Fluorescent UV-Lamp Method,
- Xenon lamp method.

Because of standardization, many test laboratories offer these tests as a commercially available service.

9.3.2. FLUORESCENT UV-LAMP METHOD

This method uses UV light from fluorescent lamps, so the colour degradation comes mainly from UV. In addition, the sample is exposed to heat and moisture. Special programs are defined, which describe heating, illumination and dew periods.

For paint, the methods are described in *ISO 16474-3* 0 and for plastic in *ISO 4892-3* 0.

The standards contain information about the UV-spectrum used, the required irradiance, temperature, condensation, measurement devices and the design of the test chamber.

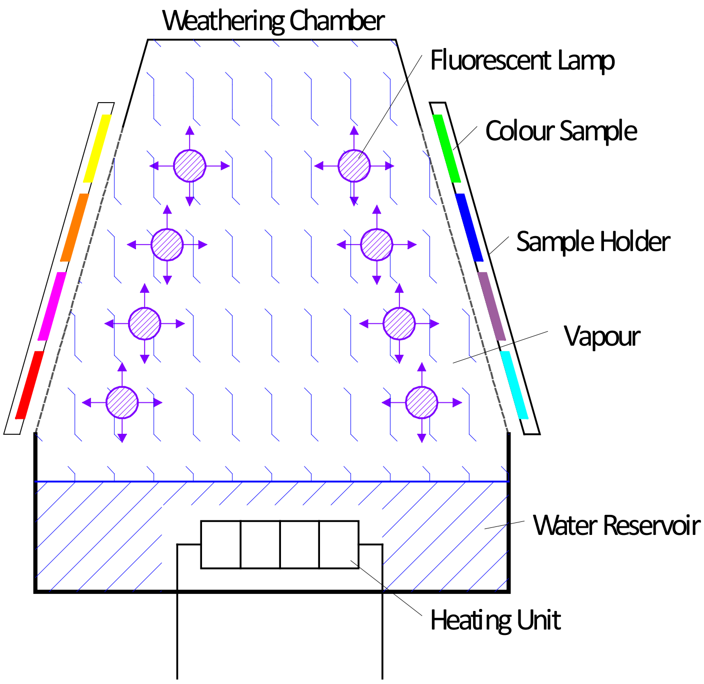


Figure 12 Principle of an artificial weathering chamber (side view)

Figure 12 shows an artificial weathering chamber, but chambers are available in different designs and cost levels.

The fluorescent lamps are positioned inside the chamber. The colour samples are at the side of the chamber and the surface to be weathered is inward-looking. The fluorescent lamps irradiate the colour samples.

At the bottom is a water reservoir with a heating unit. The water is heated so that the chamber is filled with water vapour. The vapour condenses on the colour sample. To improve condensation, the samples slope down.

The lamps and the heating are switched on and off due to the weathering program chosen.

9.3.3. XENON LAMP METHOD

In this method, the lamps are xenon arc lamps. The main difference to the fluorescent lamp method is that with filtered xenon light, the radiation used is very similar to daylight. For the spectral adjustment, special optical filters may be used. The exposure to heat and moisture is the same as for the fluorescent method.

The standards behind this method are *ISO 16474-2* 0 for paint and *ISO 4892-2* for plastic 0.

9.3.4. RESULTS FROM ARTIFICIAL WEATHERING TESTS (GERMAN EXAMPLE)

The durability of the colours tested can be easily indicated by plotting the measured chromaticity values into the CIE diagram. This is done in Figure 13 for measurements of the German Federal Waterways and Shipping Administration (WSV).

The regions shown are the accepted regions of WSV and are derived from IALA Recommendation *R0108* 0 Continuous green lines represent the accepted area of WSV before testing (delivery status). Dotted lines represent the accepted level of chromaticity of the colour when in use.

The chromaticity diagram shows the movement of the colour coordinates versus exposure time for two green colour samples.

Small blue dots on the diagram indicate every single measurement. In the delivery status the colours are highly saturated (s: starting colour, high y-value, uppermost dots of both samples). When the samples are exposed to the weathering test, the colour will fade and gets less saturated. The corresponding exposure times of each measurement are listed in the table.

In the example of Figure 13 the colour of both green samples moved towards white or grey with an inline development. Other green samples may move to blue or yellow instead but they always become desaturated.

Sample 1 on the left side lasts longer then sample 2 on the right. After an exposure time of 5.655 hours (measurement 12) it is still in the accepted region of the competent authority. Based on a mathematical extrapolation, it is expected to leave the region at about 7.800 h (red dot 'e').

Sample 2 on the right side left the accepted region already between measurement 6 and 7. The interpolated exposure time is about 2.300 h (red dot 'e').

Evaluation of the results:

a.) comparison of the fading of different colours

Artificial weathering can be used to compare the fading of different colours: From the example it can be derived that the colour of sample 1 will last more than 3 times longer than the colour of sample 2.

b.) establishment of minimum requirements for colours

Artificial weathering allows specification of minimum requirements for the fading of colours. The requirement can be the exposure time that a sample will remain in the specified colour region when subject to artificial weathering.

The derived specifications can be used for procurement procedures. The competent authority can ask for test results for artificial weathering tests according to the standards at bid-submission.

The maximum exposure time of an artificial weathering test has a correlation to real exposure in-situ. This correlation can be described by the ratio between the maximum exposure time in-situ and the artificial exposure time. For example, a buoy, which has been successfully in-situ for 12 years (12 x 8.760 h = 105.120 h) and was tested for a maximum artificial weathering exposure time of at least 5.000 h, has a correlation factor of about 21.

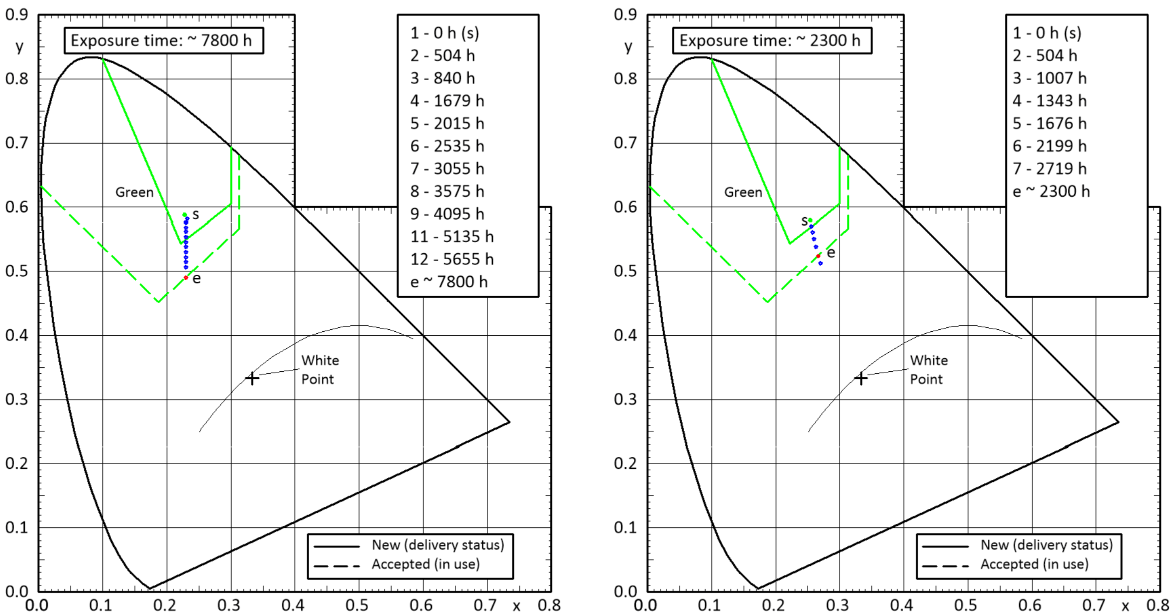


Figure 13   CIE chromaticity diagram with measurements versus time (example from WSV, Germany)

Some samples which have been weathered artificially are shown in figure 14. The area exposed to weathering shows unsaturated colour on the test sheets. Occasionally mechanical damage is visible and makes the assessment more difficult.

Figure 14   Test samples after artificial weathering (top paint / bottom plastic)

Artificial weathering tests allow comparing products according to the maximum exposure time the sample stays in the accepted colour region.

The maximum exposure time of artificial weathering test has a correlation to real exposure in-situ.

The correlation can be described by the ratio between the maximum exposure time in-situ and the artificial exposure time. For example, a buoy, which has been successfully in-situ for 12 years (12 x 8.760 h = 105.120 h) and was tested for a maximum artificial weathering exposure time of at least 5.000 h, has a correlation factor of about 21.

In practice, the correlation factor depends on different parameters:

- Material (paint, plastic, film)
- Latitude
- Temperature
- Humidity

Some parameters are not considered such as bird fouling, marine growth and corrosion.

The correlation factor may take a value from 5 to 30 depending on test parameters.

To find out a suitable factor requires more work. For further information, see references [14] and [15].

10. SYMBOLS AND ALPHANUMERIC CHARACTERS

Good legibility requires that symbols and alphanumeric characters should have sufficient contrast with the colours against which they are seen. A contrast of luminance factors is usually of more advantage than one of hues, and the ratio of the luminance factors should be made as large as is possible. Thus, black should be applied on yellow, and, in general, white should be used on red, green or blue. However, if the luminance factors of red or green are particularly high, as they may be if these colours are fluorescent, then the contrast of black may be more satisfactory. Sometimes a symbol or an alphanumeric character may be clearer if it is outlined in a contrasting colour or is shown on a distinct panel of contrasting colour.

11. COLOURS OF RETROREFLECTING MATERIALS

Two different specifications for the colours of retro-reflecting materials are required if the colours are to be defined adequately for the purposes of this document. The specifications need to define the colours for conditions of illumination that are representative of those occurring both by day and by night. With regard to this document, a specification of the colours for night-time conditions is unquestionably the more useful, but the methods of measurement have not yet been internationally resolved. A specification of the colours for daytime conditions has been undertaken by the CIE. A particular problem with a specification for daytime conditions relates to the geometry of measurement and the limits of the luminance factors. IALA Recommendation *R0106 The Use of Retro-reflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System (E-106)* refers 0.

12. COLOUR COLLECTIONS

This guideline uses the *CIE 1931 Standard Colorimetric System* 0 to specify colours by their chromaticity and luminance factors. This provides a scientifically correct method of defining colour. Although the use of chromaticity coordinates and luminance factor is well established, there are practical reasons to choose different methods to describe a colour. One of the reasons is that paint manufacturers can more easily work with colour collections.

A collection contains a number of colours and gives a name to them. Behind the collections stands an exact procedure to reproduce the surface colours.

A colour 'swatch' can often be obtained for each colour in a colour collection. These can be used to compare the colour of a surface to the 'swatch'. However, this is a subjective method and should only be used under natural light, to give an indication of how different colour appears compared to its original state. Swatches should be stored in darkness when not in use.

The use of a colour collection simplifies the definition of colour and produces a number of colours that lie within the colour regions. However, because of the strong influence of gloss on the saturation of colour, there may not be a single chromaticity coordinate for each colour.

Throughout the world, different types of colours are used depending on local circumstances. Some countries use darker colours because of light backgrounds; others need lighter colours in twilight to make the object more visible.

12.1. RAL CLASSIC COLOUR COLLECTION

The IALA regions can be achieved with the RAL CLASSIC Colour collection for glossy colour shades *RAL 841-GL* 0.

The following numbers are a subset of the RAL collection. They were chosen to ensure a high distance of recognition and good conspicuity, and so the colours have a high saturation and luminance factor.

12.1.1. ORDINARY COLOURS

Table 3 RAL colours that meet the specifications for ordinary colours

Number	Name	Luminance factor ß
RAL 3028	Pure Red	> 13%
RAL 6037	Pure Green	> 15%
RAL 1023	Traffic Yellow	> 50%
RAL 2008	Bright Red Orange	> 25 %
RAL 5019	Capri Blue	> 7%
RAL 9016	Traffic White	> 80%
RAL 9017	Traffic Black	< 1%

There are other RAL-Colours that meet the specifications but are not as saturated as the colours shown in Table 5.

12.1.2. FLUORESCENT COLOURS

Table 4 RAL colours that meet the specifications for fluorescent colours

Number	Name	Luminance factor ß
RAL 3024	Luminous Red	> 25%
RAL 6038	Luminous Green	> 25%

For the fluorescent colours orange and yellow, there are no RAL numbers that meet the specifications of this Recommendation.

12.2. RECOMMENDED NATURAL COLOUR SYSTEM (NCS) COLOUR NUMBERS

NCS is a system with the help of which all conceivable surface colours (not fluorescent or metallic colours) can be described 0.[1]

Table 5 NCS colours that meet the specifications for ordinary colours

NCS-Code	Name	Equivalent RAL
S 1085-Y80R	Red	---[2]
S 2070-G10Y	Green	---
S 1080-Y	Yellow	RAL 1023
S 0585-Y40R	Orange	RAL 2008
S 4050-R90B	Blue	RAL 5019
S 0500-N	White	RAL 9016
S 9000-N	Black	RAL 9017

13. DEFINITIONS

The definitions of terms used in this IALA guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

14. ABBREVIATIONS

CCD	Charge Coupled Device
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM
NCS	Natural Colour System (Sweden)
nm	nanometre
RAL	RAL colour system (Reichs-Ausschuß für Lieferbedingungen und Gütesicherung)
UV	Ultra Violet (light) (10 – 380 nm)

15. REFERENCES

IALA. (2017) Recommendation R0108 Surface Colours Used as Visual Signals on Marine Aids to Navigation (E-108) Edition 4.1

1 The recommended colours for NCS for green and red are not equivalent to the recommended RAL Colours

2 The recommended colours for NCS for green and red are not equivalent to the recommended RAL Colours

CIE. 1931 Standard Colorimetric System has become a Joint ISO/CIE Standard On Colorimetry: ISO 11664-1 / CIE S014 (series of standards).

CIE. (1983) No. 39.2, Recommendations for Surface Colours for Visual Signalling (2nd ed.),.

CIE. (2004) No. 15, Technical Report: Colorimetry,.

IALA. (2017) Recommendation R0106 The Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System (E-106), Edition 2.1

RAL-Colour Collections: www.ral-farben.de, RAL Gemeinnützige GmbH, St. Augustin, Germany.

NCS. Natural Colour System: www.ncscolour.com, NCS Colour AB, Stockholm, Sweden.

NCS. (July 2007) Translation Key NCS RAL, (with English, French, Swedish and German translation).

ASTM E2152 Standard Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data, American Society for Testing and Materials, United States of America

EN ISO 16474 - Paints and varnishes - Methods of exposure to laboratory light - Part 3: Fluorescent UV lamps

EN ISO 4892 - Plastics - Methods of exposure to laboratory light - Part 3: Fluorescent UV lamps

EN ISO 16474 - Paints and varnishes - Methods of exposure to laboratory light - Part 2: Xenon arc lamps

EN ISO 4892 - Plastics - Methods of exposure to laboratory light - Part 2: Xenon arc lamps

Sealite. ‘Hot Climate Presentation´ by John Corio

SeaHow Report ‘Colour Stability of Navigation Buoys’ by Solar Simulator, Finland, 2016

AN EXAMPLE OF A SWATCH TEST KIT (FINNISH TRANSPORT AGENCY)

LIST OF CONTENTS:

More information: Finnish Transport Agency, Sami Lasma. 029 534 3341
Liikennevirasto

PURPOSE OF THE GUIDELINE

This material provides guidelines on the colour assessment of existing plastic pipe buoys.

The fading of colours is assessed as part of field work with the help of colour models.

The colour models have been made from buoy materials supplied by Meritaito Oy and RotationsPlast AB.

The change of colours illustrated in the colour models can also be utilised in the assessment of other plastic buoys currently in use and where applicable in the assessment of painted steel buoys.

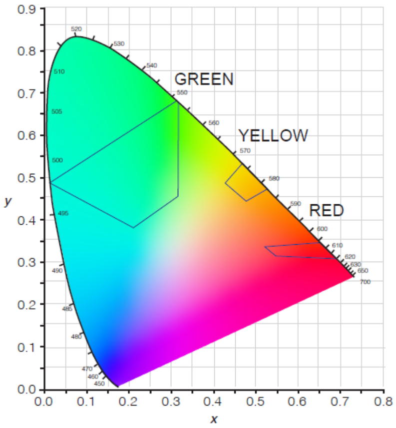
More information: Finnish Transport Agency, Sami Lasma. 029 534 3341
Liikennevirasto

4.

SPECIFIED COLOUR TONES OF NAVIGATION BUOYS

The colour tones used in buoys – green, red and yellow – are specified in the accompanying colour chart CIE1931. IALA recommendation E-108.

The demarcated areas in the colour chart show the tones that the surface colours should comply with. According to the measurements performed, the colours of the new plastic buoys are in the areas specified.



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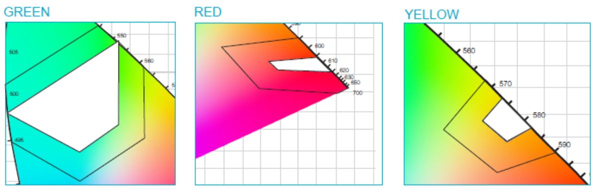
5.

HOW COLOURS CHANGE

Colours change over the years in particular due to sunlight and the UV radiation it contains. As the tone of the colour changes, the place of the colour shifts on the colour chart, and the colour may begin to slip out of the acceptable colour range.

The colour chart is used to observe that in addition to changes in colour tones, the colour may change into a completely different colour.
- Green can become blue or yellow
- Red can become orange
- Yellow can become orange



In the images the white area illustrates the acceptable colour. The outlined area outside of the white area includes those colours to which the intended colour can change as time goes by.

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Liikennevirasto

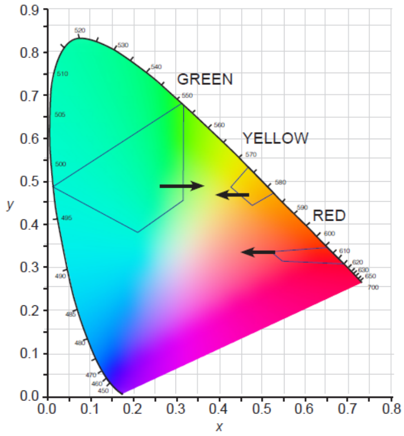
6.

HOW COLOURS CHANGE

Practical experience and testing performed on plastic buoys show that most plastic materials currently in use fade.

In the image, where the arrow points, it shows the tone of a new buoy, and the direction of the arrow shows how the tone changes.

Recognition of the buoys becomes difficult especially in bright light or when visibility is limited.



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Liikennevirasto

7.

ACCEPTABLE CRITERION

The colour models demonstrating fading are made from the very same plastic buoy materials as the buoys themselves.

Three reference colours are provided for each buoy colour.

A New and unused

B The colour change is detectable, but the change in the tone is acceptable.

C The buoy must be replaced due to excessive colour fading.

To demonstrate fading, the red colour models have been photographed against new buoy colours in studio conditions.

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Liikennevirasto

8.

USE OF COLOUR MODELS

1. First, the buoy is brushed clean using seawater, so that the loose dirt is removed and the true colour of the plastic buoy becomes visible.
2. Valitse valmistajan mukainen oikea väri (Meritaito tai RotationsPlast). Molemmille valmistajille on omat värimallinsa.
3. Then reference colour A - new and unused - is placed to the surface of the buoy.
4. If you notice that the buoy has faded more than that, use reference colour B.
5. If the buoy has faded even more than reference colour B, move on to the third reference colour (C).
6. If the buoy has faded more than the third reference colour (C), the buoy should be replaced with a new one.

! The navigation buoy and colour model must be viewed from directions from which bright sunlight and reflections cannot alter the observation.

More information: Finnish Transport Agency, Sami Lasma. 029 534 3341
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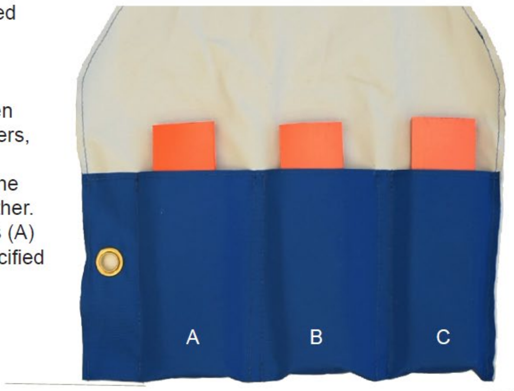
9.

STORAGE OF COLOUR MODELS

The colour models must be stored protected from sunlight in their own protective bags.

Specific colour models have been made for both of the two producers, Meritaito and RotationsPlast, because the original colours of the buoys differ slightly from each other. Nevertheless, all original colours (A) are within the colour ranges specified by IALA.

The colour model (C) is outside of IALA region.



More information: Finnish Transport Agency, Sami Lasma. 029 534 3341
Liikennevirasto

10.

MAKING OF COLOUR MODELS AND NAVIGATION BUOY TESTING

The colour models have been realised using accelerated weather testing. Samples have been subjected to strong solar radiation – up to triple that of normal levels – and to continuous light for thousands of test hours. The sample temperature has been maintained as low as possible so the samples do not change due to excessive heat.

Testing and research on buoys and related equipment have been performed in co-operation for several years.

Solar Simulator
Scientific Testing

More information: Finnish Transport Agency, Sami Lasma. 029 534 3341
Liikennevirasto

11.

LABORATORY MEASUREMENT

A.1. SELECTION OF MEASUREMENT POINTS

a. Select 3~5 measurement points of each colour for the same sample to be measured;

b. Scatter the measurement points selected.

A.2. MEASUREMENT PROCEDURES

a. Measurement of Ordinary Colours and Retro-reflecting Materials in day-time conditions：

1 Calibrate the measurement instrument with the zero calibration device.

2 Use the white standard plate to calibrate the instrument after the zero calibration of the instrument is accomplished.

3 Place the sample to be measured, measure and obtain the spectral reflectance of the measured points of the sample after the white standard calibration.

b. Colour measurement of Fluorescent Materials

- Polychromatic Light Irradiation Method

  1 Calibrate the measurement instrument with the zero calibration device.

  2 Use the white standard plate and the fluorescent standard plate to calibrate the instrument after the zero calibration of the instrument is accomplished.

  3 Place the sample to be measured, measure and obtain the spectral reflectance of the measured points of the sample after the calibration is completed.

- Monochromatic Light Excitation Method

  1 Place the sample to be measured, and obtain the Donaldson Matrix for the measured points of the sample with the 10nm wavelength interval(including the reflecting component and fluorescent component of the sample, according to Standard ASTM E2153).

  2 Calculate the total spectral radiance factor of the measured sample, i.e., the final value for subsequent color parameter calculation.

ON-SITE MEASUREMENT

A.3. SELECTION OF MEASUREMENT POINTS

a. Select 3~5 measurement points of each colour for the same sample to be measured;

b. Select the measurement points in the direction of navigation observation;

c. Scatter the measurement points selected.

A.4. MEASUREMENT PROCEDURES

a. Measurement of Ordinary Colours and Retro-reflecting Materials in day-time conditions:

1 Calibrate the measurement instrument with the zero calibration device.

2 Use the white standard plate to calibrate the instrument after the zero calibration of the instrument is accomplished.

3 Place the sample to be measured, measure and obtain the spectral reflectance of the measured points of the sample after the white standard calibration.

b. Colour measurement of Fluorescent Materials:

1 Calibrate the measurement instrument with the zero calibration device.

2 Use the white standard plate to calibrate the instrument after the zero calibration of the instrument is accomplished.

3 Use the fluorescent standard plate to calibrate the instrument after the calibration of the white standard plate is accomplished.

4 Measure the AtoN and obtain the spectral reflectance of the measured points after the calibration.

5 Obtain the measurement result of different UV radiation components through the adjustment of UV components of light source.

MONOCHROMATIC LIGHT EXCITATION METHOD

The monochromatic light excitation method is the most precise method for measuring fluorescent colour. The measurement equipment consists of two separate monochromators (figure D1). The irradiation monochromator produces monochromatic light to illuminate the sample. The viewing monochromator analyses the radiation leaving the colour sample. With this method, the radiation-transfer properties of fluorescent material become independent of the specific illuminant spectrum.

The result of the measurement is a two-dimensional array of bispectral photometric values. It is obtained by setting the irradiation monochromator at a series of fixed wavelengths (μ) in the ultraviolet and visible range, and for each μ, using the viewing monochromator to record readings for each wavelength (λ) in the visible range.

The resulting array is called the 'Donaldson Matrix'. The value of each element (μ, λ) of this array is described as the Donaldson radiance factor ($D(\mu, \lambda)$). It is an instrument and illuminant-independent photometric property of the sample.

To get the emitted spectrum of a colour sample with a specific light source, it is necessary to calculate the stimulus function according to Equation D1. From the calculated stimulus function the Tristimulus Values are derived in the usual way (Equation D2).

The advantage of this method and the Donaldson matrix is that they provide a characterization of the sample’s radiation-transfer properties, without the inaccuracies associated with source simulation and various methods of approximation.

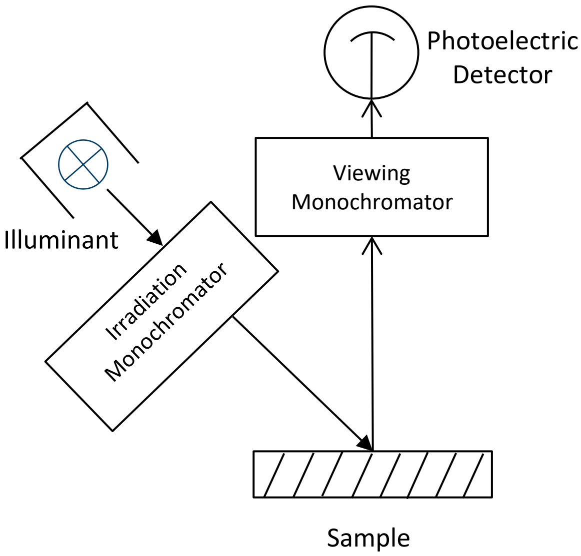


Figure D1 Component Parts of a two-monochromator system

The calculation of tristimulus values with the Donaldson radiance factor ($D(\mu, \lambda)$) are as follows:

$$F(\lambda) = \sum_{\mu=300}^{780} \Phi(\mu) D(\mu, \lambda)$$

Equation D1 Stimulus Function

Where:

$F(\lambda)$ is the sample's stimulus function (relative spectral radiance),

$\Phi(\mu)$ is the relative spectral power of the standard illuminant Φ at the element's irradiation wavelength(μ).

$$X = k\sum_{\lambda=380}^{780}\bar{x}(\lambda)F(\lambda)$$
$$Y = k\sum_{\lambda=380}^{780}\bar{y}(\lambda)F(\lambda)$$
$$Z = k\sum_{\lambda=380}^{780}\bar{z}(\lambda)F(\lambda)$$

Equation D.2 CIE1931 Tristimulus Values

Where:

k is the normalization constant, $k = \dfrac{100}{\sum_{\lambda=380}^{780}\Phi(\lambda)\bar{y}(\lambda)}$,

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are *CIE 1931* standard observer.

For further information, see *ASTM E2152 Standard Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data, American Society for Testing and Materials, United States of America.*

SPECTRAL MISMATCHING OF COLOUR MEASUREMENT BY PHOTOELECTRIC INTEGRATION METHOD (COLORIMETER)

Photoelectric integration method (with Colorimeters) performs integrating on the measured spectral power by matching the spectral response of the detector to the CIE standard colorimetric observer $\bar{x}(\lambda)$、 $\bar{y}(\lambda)$、 $\bar{z}(\lambda)$, to get the related colour parameters of the samples, as shown in figure E1.

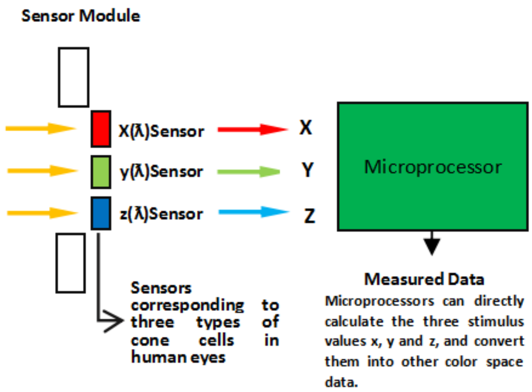


Figure E1 The principle of photoelectric integration method

In fact, there is always a spectral mismatching problem in this method with the limitation of technology. The relative spectral sensitivity of the detector cannot match perfectly with the curve corresponding to the standard observer $\bar{x}(\lambda)$、 $\bar{y}(\lambda)$、 $\bar{z}(\lambda)$, and there is somewhat deviation. Generally, f_{lx}' , f_{ly}' , f_{lz}' are used to evaluate the spectral mismatching degree of the detector. The larger the value is, the worse the matching degree is, the greater the error of the measurement result will be, especially for the red, blue and other colour visual AtoN samples.

$$\begin{cases} \mathrm{f}_{1x}' = \dfrac{\sum \left| S_x(\lambda)_{rel} - \bar{x}(\lambda) \right| \Delta\lambda}{\sum \bar{x}(\lambda)\Delta\lambda} \times 100\% \\ \mathrm{f}_{1y}' = \dfrac{\sum \left| S_y(\lambda)_{rel} - \bar{y}(\lambda) \right| \Delta\lambda}{\sum \bar{y}(\lambda)\Delta\lambda} \times 100\% \\ \mathrm{f}_{1z}' = \dfrac{\sum \left| S_z(\lambda)_{rel} - \bar{z}(\lambda) \right| \Delta\lambda}{\sum \bar{z}(\lambda)\Delta\lambda} \times 100\% \end{cases} \qquad \text{(C.1)}$$

$S_i(\lambda)_{rel} = \dfrac{\sum S(\lambda)_A \bar{i}(\lambda)\Delta\lambda}{\sum S(\lambda)_A S_i(\lambda)_{mea} \Delta\lambda} \cdot S_i(\lambda)_{mea}$, $i = x, y, z$, $S(\lambda)_A$ is relative spectral power distribution of standard source A, $S_i(\lambda)_{mea}$ is spectral sensitivity curve of detector.

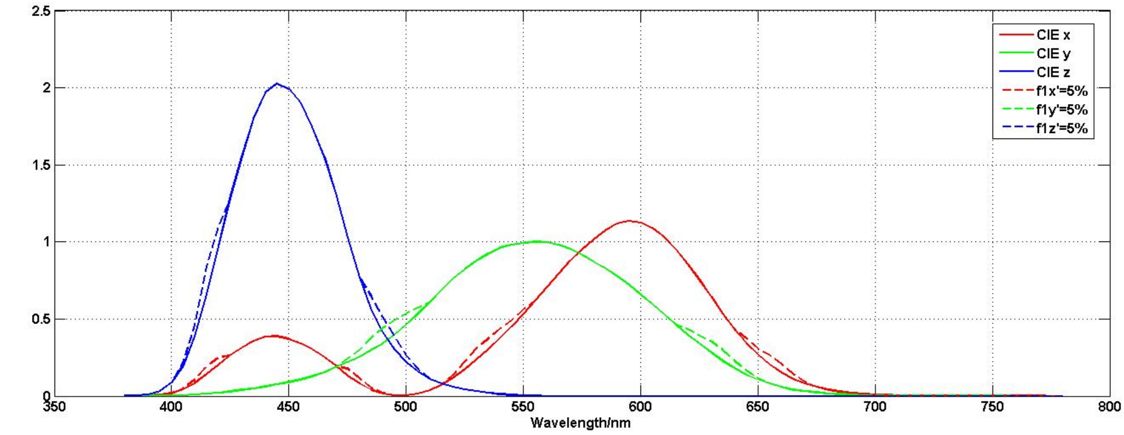


Figure E2 Simulation of detector with 5% of f_{lx}', f_{ly}' and f_{lz}'

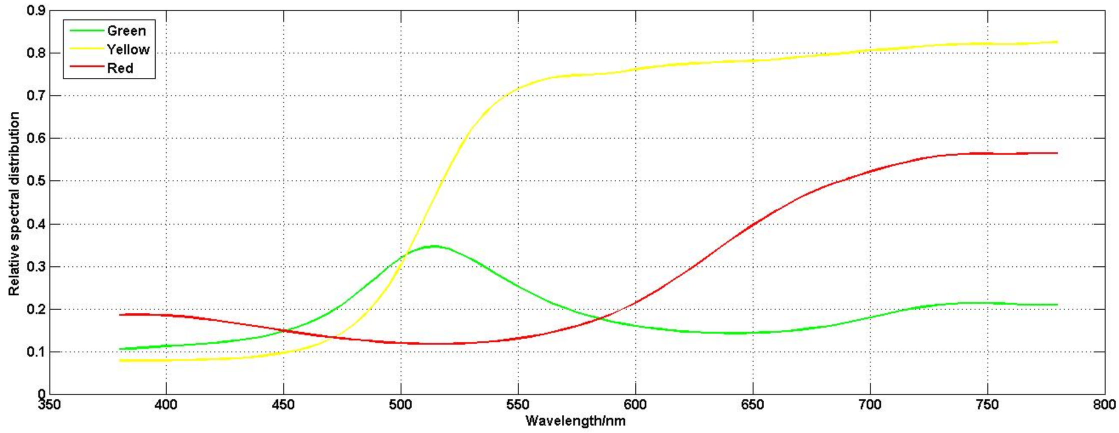


Figure E3 Typical red, green and yellow colour samples (left) and their spectral distribution (right)

In the research process, the detector system with f_{lx}', f_{ly}' and f_{lz}' as shown in Figure E.2 is simulated to measure the chromaticity coordinates of typical red, green and yellow colour samples as shown in Figure E.3. The measurement results are shown in Table 1. When $f_{lx}' = f_{ly}' = f_{lz}'$ = 5%, the chromaticity coordinate error is as high as 0.0031. While in the market, there are more detector systems with $f_{lx}' = f_{ly}' = f_{lz}' \geq$ 7%. In addition, if there is a narrow-band spectrum in the spectrum of the sample to be measured, the detection error will be greater. Therefore, spectrophotometry method is recommended for high-precision colour measurement.

Table E1 Measurement results of detector spectral mismatch

Mismatch error \ **Chromaticity coordinates**		Red		Yellow		Green	
		x	y	x	y	x	y
0%		0.3466	0.3101	0.2632	0.4733	0.2903	0.4127
5%	Result	0.3471	0.3089	0.2638	0.4741	0.2894	0.4158
	Deviation	-0.0005	0.0012	-0.0006	-0.0007	0.0009	-0.0031