Chapter 1

A colour contrast assessment system: design for people with visual impairment

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1.1. Colour contrast assessment model and system development

Visually Impaired People (VIP) encounter difficulties with the perception of products and environments in their everyday life such as a door in a wall or column on a station concourse. Contrast can be an essential and vital aid for negotiating the world for people with low vision (Bright et al 1997). The development of a colour contrast assessment system would enable the construction and design sectors to create more accessible spaces and objects.

A requirement of perception by the human eye is to be able to assess the visual contrast between adjacent surfaces or edges of material objects and judge distances. This function is one of two distinct systems in human vision, a fast, contour-extracting system (Ramachandran *et al*, 1998). Contrast is now included in guidelines for accessibility for design of environments, products and services for VIPs; Building Regulations Part M, 2004, the Disability Discrimination Act (DDA), 2004, and BS Light Reflectance Value (LRV) of a surface (BS 2008). However despite standards and regulations, there are no ‘tools’ to help professionals establish ‘good colour contrast’ for their projects. Mechanisms for the provision of interventions - for achieving success - had not yet been fully mapped out. So no definitive advice existed on how effective colour contrast could be achieved easily and inexpensively. Colour contrast assessment can be a confusing or complex process. For example access personnel may not be able to devote much time or resources to it. Also, existing colour measurement technology (spectrophotometry) is too expensive (circa £4 - 8,000) and over-specified (multiple colour spaces) for simple and easy contrast evaluation.

A software prototype for automated prediction of visibility for the detection of contrast thresholds was established using data derived from testing with two sets of visually impaired volunteers; twenty two VIPs and six control group in a ‘real world’ viewing of 380 objects, then a stratified group of ten VIPs across the visual ability range V1 to V10 who took part in validating the software in the laboratory. A system model which has been developed is the basis of on-line software, a prototype measurement tool and a colour contrast guide for the design, manufacture and planning of product design and buildings. The work has led to the creation of a first generation algorithm for firmware to be used in a tool microchip.

The growing importance of accessibility to an expanding aging population motivates this study of vision and visual impairment in a ‘real-world’ context. A major advance in this work was the establishment of five key factors which affect visual acuity, including contrast, for assessing the visibility of designs in a real world context. The colour contrast assessment model - developed by Dalke, Conduit and Conduit enables architects, designers, access consultants, and developers of the built environment to predict whether a person with low vision is able to see an object, text or element of a product or building component before and after manufacture or installation.

Nearly 3 million people in the UK have some form of low vision. Around 2% of the registered VIP population (classified as severely impaired or blind) have no ability *‘to see any light at all that may be coming through a window’* (V1), and 4% may just be able to perceive light (V2). A useful scale of visual ability maps the population from V1 to V10 (Table 1.1). Experts in the field recognize that the number of registered VIPs does not reflect the actual scale of low vision in the UK; people with poor visual acuity may not present themselves to either GPs or opticians for early diagnosis so the statistics making research in this area even more pressing.

Table 1.1 Visual ability categories and percentage gross figures for visual ability levels V1-V9, age 16+. Ability level is measured with any desired vision aids. Dalke et al, 2008, Grundy E., 1997, Douglas, G., 2006

V1	Cannot tell by the light where the windows are	2%
V2	Cannot see the shapes of furniture in a room	4%
V3	Cannot recognise a friend if close to his/her face	7%
V4	Cannot recognise a friend who is at arm’s length away	9%
V5	Cannot read a newspaper headline	11%
V6	Cannot read a large print book	13%
V7	Cannot recognise a friend across a room	16%
V8	Has difficulty recognising a friend across the road	18%
V9	Has difficulty reading ordinary newspaper print	20%
V10	Full vision ability	-

People who experience some form of ocular disease may also have colour vision impairment (Marshall, 1991, Adams, 1990). Although colour vision may be impaired, VIPs can usually discriminate between two adjacent surfaces in terms of the difference between their Light Reflectance Values (LRV), known as contrast (Bright *et al* 1997). The LRV of a surface is defined using the Commission International d'Eclairage (CIE) 1931 colour space; it is the Y value of the light reflected by the surface illuminated with the CIE D65 standard illuminant.

The model for perception explored here was investigated after observations during an EPSRC/Link research project (Dalke *et al*, 2004). We saw that a coherent use of contrast would improve visibility of environments and be efficacious for the community of VIPs. Colour contrast and lighting were identified as two of five key factors making the environment accessible; the three others being visual ability of the target group, the dimension of the object text or element, and its distance from the observer. A strategy to develop a model took into account these five key factors to predict which VIP groups could distinguish the object, text or element. We first describe the collection of the data before outlining the development of the vision model then finally we describe the website and manual that has made the model readily available to access personnel, architects, the construction industry and designers.

1.2. Vision research

In earlier work, (Dalke *et al*, 2002) data was gathered while testing VIP participants at three transport sites. For these 'Real World' site tests, vision testing required establishing the vision capability of all the participants. They were a mix of gender and age, and both visually impaired and fully sighted control group volunteers. The range of visual acuity results for the participants ran from 20/21 to 20/380, with a mean of 119. Some results of these observations showed clear design directions for the high visibility of signage for example in public spaces (Figure 1.1).

Figure 1.1 Signage with a success rate of 86 – 100% of being seen by VIPs at a station site.

Visual acuity and function improved dramatically with an increasing light level, which is a significant design intervention for VIPs in the man-made world. Although five factors determine the ability to perceive objects, text and surfaces, Lux levels provide the critical factor to perception depending on user's abilities. Standards and recommendations for lighting specific environments do exist and vary considerably according to the variables of user and task (CIBSE 1994, CIBSE 2008, CIE 1997).

Table 1.2 Examples of measurements of objects, signs and elements examined at a bus station. The categories of data were: eye levels of participants; distance of object from the observer; lux vertical and horizontal levels in the vicinity of the object; dimensions of the item; visual angle; the light reflectance value (LRV) or luminance of the object and whether it was seen or not.

	Object 1	**Object 2**	**Object 3**	**Object 4**
Seen	Seen/Yes	Seen/Yes	Seen/Yes	Seen/Yes
Av. eye level (m)	1.544	1.544	1.544	1.544
Max eye level (m)	1.75	1.75	1.75	1.75
Min eye level (m)	1.42	1.42	1.42	1.42
Distance	6.45m	6.45m	5.5m	6.5m
Lux Vertical	8350	8350	8350	4060
Lux Horizontal	13190	13190	13390	6260
Height off ground	1.98	0.91	N/A	N/A
Width of object	0.61	2.59	N/A	N/A
Height of object	0.61	0.88	N/A	0.43
Visual A V	5.3	7.8	0.0	3.6
Visual A V (max)	5.4	7.8	0.0	3.6
Visual A V (min)	5.3	7.8	0.0	3.7
Colour 1 LRV	1	78	N/A	N/A
Colour 1 Descript	Black	White	Off-white	Grey

These detailed measurements of 380 objects (seen by VIPs) in their environs – namely the surfaces' Light Reflectance Value (LRV), then size, distance from an observer and lux levels on 'real world' sites were collated in further studies (Table 1.2). Analysis of the data revealed a strategy for defining critical points for perception of the environment by VIPs. In these new studies key factors were established for defining perception of objects and environment elements.

1.3. Model development

The model depended on the five key factors: visual ability of the observer f ; the tonal contrast difference of the object to background, t , the lighting intensity, l , the projected width w and height h of the object, and the distance d from the object to viewer. These parameters are summarised in Figure 1.2. The model aimed to link these concepts to predict the fraction of 'Viewers' able to see the sign, f . In order to simplify the model we assumed that vision depends just on the visual angle of the object, which can be calculated from the distance, width and height with

$$\theta = 2\arctan\left(\frac{\min(w,h)}{2d}\right) \tag{1.1}$$

Formally, one should factor in the effect of the different heights that objects were off the ground, compensated for by the average eyelevel of the 'Viewers'. This tended to have little effect on the results when assessed since critical objects are typically at ground to eyelevel, and much further away than their elevation.

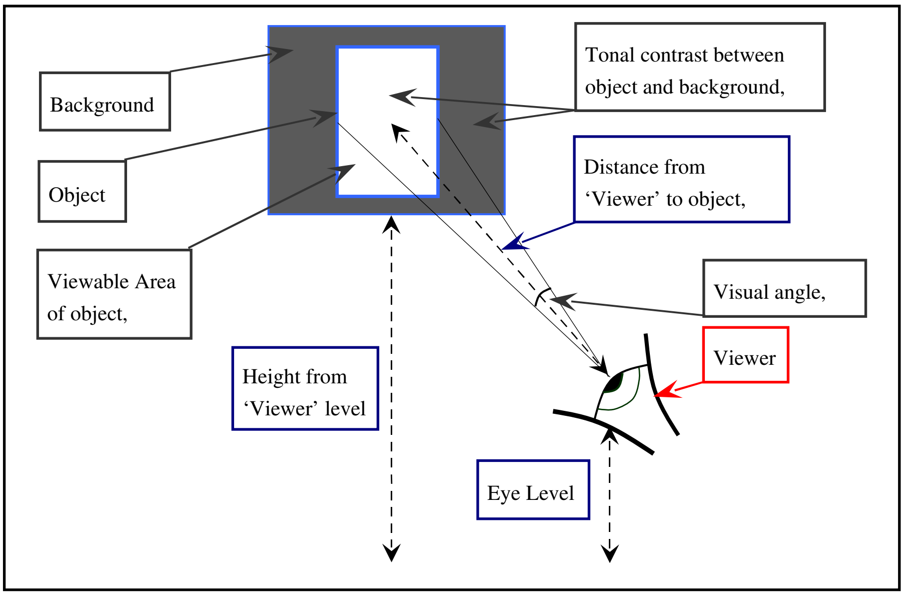

Figure 1.2 The object and 'Viewer' in the model

1.3.1. Choice of model

To use the key factors of tonal contrast, lighting, and visual angle to predict the fraction of 'Viewers' able to distinguish a sign we developed a numerical algorithm that we calibrated using the 'real world' data. In designing a suitable algorithm we assumed that each of the key factors affects the critical fraction independently. Therefore the model for the critical fraction is written in the form

$$f(l,\theta,t) = L(l) \times \Theta(\theta) \times T(t) \tag{1.2}$$

Each of the functions $L(l)$, $\Theta(\theta)$, and $T(t)$ represent a separate model for light intensity, visual angle, and tonal contrast respectively. This factorization simplifies the model by allowing us to consider each of the parameters separately.

This functionality has the additional benefit that it can be readily numerically calculated and is also easily invertible, allowing, for example, the model to make a prediction for the critical tonal contrast. We assume each of these functions can be modelled by the physically motivated cumulative normal (Gaussian) distribution. This tells us what fraction of the 'Viewers' are able to interpret the object as its parameter is varied. For example, Figure 1.3 shows the variation in the fraction of 'Viewers', L able to interpret the object with lux level l. In strong light nearly everyone can interpret it so L is approximately one. In dim light very few can interpret it so L is almost zero. In intermediate light, where about half the 'Viewers' can interpret the object, the distribution decreases rapidly with the light level. Here the number of 'Viewers' that can view the object falls rapidly. The median (denoted by a bar) light level $\bar{l}$ $\bar{l}$ of the distribution is given when half the 'Viewers' can interpret the object. The range of lux values over which the majority of the population (68%) can interpret is $\bar{l} \pm \sigma_l$, the standard deviation.

The parameters used to develop the model are derived from observations on previous data gathered from VIP volunteers (the 'Viewers') at each of three 'real world' sites. Objects, texts or elements were tested creating data sets, which were later reduced to 144 robust sets of data (Dalke *et al* 2004). Our model gives criterion for a required fraction of 'Viewers' to be able to interpret an object, text or element. Since data was collected from various different 'Viewers' at different sites, we had to assume that the 'Viewers' presented the same gamut of impairment types and levels of residual vision on each site. This reflects the breadth, types and variations of vision loss which introduces random error into the result.

Table 1.3 Example input data and ranges

Symbol	**Example data**	**Range of possible data**	**Definition and description**
f	V4	V1-V10	Fraction of 'Viewers' able to view the object – Visual Ability Groups
t	55	5-85	Tonal contrast – the difference between the Light Reflectance Values (LRV) of two visually adjacent surfaces
l	800lux	80-28000lux	Intensity of the lighting on and around the object, text, element
w , h	2m	0.1m-6.7m	Width and height of object, text, element
d	5m	2.5m-80m	Distance from object to viewer

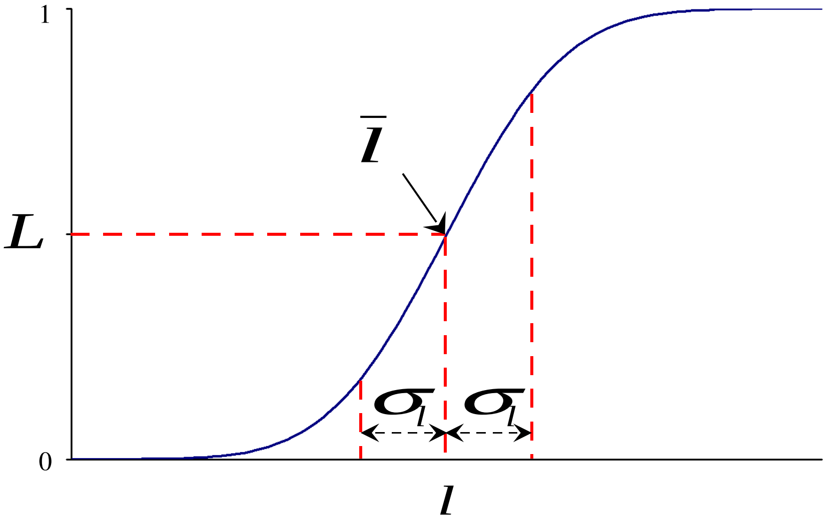

Figure 1.3 The cumulative normal distribution, $\bar{l}$ is the median Viewer light level, σ_l is the standard deviation of Viewer critical distances.

1.3.2. Validating the model

The first generation model required validation in the lab but with observations conducted in a slightly more complex near 'real world' setting (Figure 1.4). There were ten participants from Visual Acuity (VA) levels V1 to V10 who tested the software predictions of the visibility of 2187 gray scale patches against the 10 gray scale backgrounds. Over 1000 separate measurements were taken as part of the validation and testing.

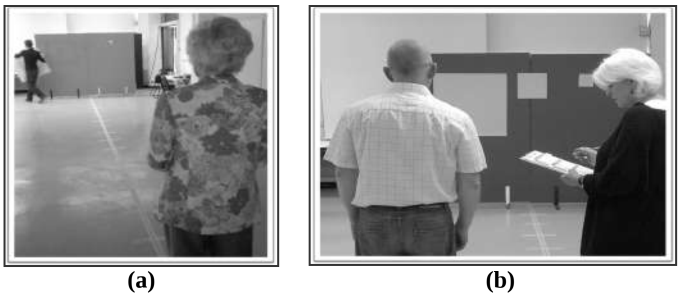

Figure 1.4 Testing – (a) Setting up the test showing the 10 metre test distance. (b) A participant observing the gray scale shapes on a dark background

The participants were invited to observe the gray scale boards of 5, 10, 21, 27, 40, 53, 62, 71, 82, 93% LRV, on which were placed patches of the same gray scales from 5 – 93% LRV in different sequences (Figure 1.4). All grayscales were measured with a spectrophotometer (xyY), tested with a range of different size square patches 0.15, 0.30 and 0.75m. and each test was conducted in a controlled lux level. A floor grid of 0.5 metre provided the participants with a central line (Figure 1.4 a) along which they walked until able to see any patch on the board. The distance from the participant to the observed patch on the board was recorded.

The colour contrast model predictions were checked and shown to be robust when compared with the data generated in the validation lab tests and these predictions made using the system would therefore be safe and reliable.

1.4. Real-world deployment and concluding remarks

We have developed a new model of object, text or element visibility and rigorously tested the accuracy of the prediction software established against the extensive validation test results. An interactive website has been created to enable automated use of the model by end users. Any combination of the key factors for visibility by VA groups may be entered into the website as parameters to estimate the threshold of viewers able to distinguish the object. If all five parameters of the key factors are entered, a result of either VISIBLE or NOT VISIBLE by the VA group/s, will be produced. If between two and five parameters are entered the website suggests the values that are missing to achieve a final result of VISIBLE. These suggestions are achieved by manipulating Equation (1.2) to find the product of the functions of the missing parameters (e.g. $L(l)$ for Lux Level), assuming the values of these functions are equal, and applying the inverse of each function to this value. The website was programmed with PHP and integrates with a database.

In addition a prototype tool/device was developed to measure one of the key inputs to the model, tonal contrast (*t*), defined as the difference between the Light Reflectance Value (LRV) of the two surfaces. The LRV of a surface is defined using the CIE 1931 colour space; it is the Y value of the light reflected by the surface when illuminated with the CIE D65 standard illuminant (scaled such that a perfect reflector has an LRV of 100 and a perfect absorber has an LRV of 0). The tool is designed for rapid on-site measurements and calculation of tonal contrast between surfaces, which (when compared with the required tonal contrast value obtained from the model) would allow designers to evaluate proposed materials for the design of products or buildings for optimum visibility. The prototype tool uses a MAZeT MTCS-TIAMI colour sensor head, which contains an array of photodiodes with colour filters producing spectral sensitivities close to the CIE 1931 2 degree observer. The light sources are white surface-mount LEDs with a 45 degree incident/0 degree reflected optical path. In the prototype, tonal contrast is calculated by an on-board microcontroller and displayed to the user; future developments will incorporate visibility prediction model to give a direct readout of visibility. Testing the prototype on a Gretag-Macbeth Colour-Checker showed that, when compared with readings from an X-Rite Spectrophotometer 962, (D65 10 degrees specular excluded 8MM $45^{0)}$, there was a 96% agreement with an average error of 2.49 on the Y value. However a skew on the blue and green hue angle (CIELch) was exposed, due to the difference between the LEDs spectrum and the D65 illuminant. Further work is planned to develop the prototype tool.

Finally the system has a colour contrast guide for quick reference on-site decision-making; it provides the data on required visual contrast of products or materials. This document was created using the software model and consistently used two fixed key factors, that of visual ability and lux level. The guide is the final component of an intended low-cost entry system for the specification of contrast in product and environmental design.

Several objectives of the integrated design research studies were achieved. Firstly, the utility and development of the prediction software for contrast was rigorously tested and its accuracy established against the extensive validation test results. The software has been used to create the guide. A prototype tool was developed that can achieve accurate LRV measurements and calculate contrast difference between any two solid opaque surfaces in products or environments. Finally this integrated system of colour contrast assessment is available for all professionals who need information about contrast specification that is easy and accessible.

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