Chapter X

Visibility Prediction Software: Five Factors of Contrast Perception for People with Vision Impairment in the Real World

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X.1 Contrast and Vision Impairment

The use of colour contrast in the built environment for people with low vision has been largely unsupported for architects, access consultants or designers, with little information available and no easy-to-use tools. Accessible environments assist everyone including vision impaired people (VIP); yet often people can be disabled by buildings, not directly by their impairment (Pullin, 2009); in 2002 a total of 0.6% of the world's population were listed as blind (Harle and McLannahan, 2008). A recent critique of accessibility recommendations showed a lack of understanding of the five key factors we identified for predicting an object's visibility (Dalke, 2011) namely, visual ability (VA) of the observer, contrast, lux level, dimension of the object and distance away from the observer. These were established as fundamental for the perception of objects, texts or elements for vision VIP, contrast being one of those five interdependent variables (Dalke *et al*., 2010); they are fundamental to the software that has now been developed to predict object visibility. The research carried out revealed gaps in how to achieve contrast practically for the professionals who should be more familiar with the process. In the USA, the ADA Standard for Accessible Design makes reference to contrast but it is ambiguous and open to interpretation. In the 1991 standard, 70 points of contrast difference is prescribed for marking warnings on walkways (ADA, 1991). But how to gauge contrast, by calculating the difference between the light reflectance values (LRV) of two surfaces is always missing. In the UK there are no advances on how to check and deliver on contrast for accessible buildings and products (DDA, 2004; EHRC, 2010).

Previous studies conducted in a laboratory, in simulated real-world scenarios and on real-world sites (Dalke *et al*., 2010) indicated that contrast difference is critical for perception of the world for people with low vision (Rogers-Ramachandran and Ramachandran, 1998). Luminance is vital for visual accessibility (ANSI/IESNA, 2007); it is not the absolute difference in luminance that is important, but the relative difference, expressed as contrast (Barten, 1999).

Colour is not that significant for accessibility. It can increase perception if people have good colour vision, but 8% of the total male population may be colour vision impaired; people may also be coping with multiple disabilities (Goldsmith, 1967). There is an infinite variation in visual capacity, acuity, and fields of vision of the partially sighted community so perception prediction is a challenge.

In real-world investigations into what visually impaired people actually see and how they use contrast and lighting to navigate we identified key factors for perception and defined V4+ mathematically as a boundary for the software by averaging participants during the tests. Findings from research highlighted: the disabling effects of glare from white surfaces with black text, rendering them painful or even impossible to read; the beneficial impact of raising lux levels by even just 50 lux; the importance of graduating lighting levels to assist adaptation to changes from exterior to interior illumination. Not surprisingly the performance of VIP participants was better in lab tests, without the compounding variables of visual noise in real-world settings. The final iteration of the software was derived from experimentation in everyday environments, with VIPs and released as an app on the iPhone using the interdependent five variable factors; two of the five are fixed - the VA at 4 and currently the lux at 400. Contrast, dimension and distance are selectable using sliders on the screen which deliver a result of VISIBLE or NOT VISIBLE. The app has been tested in real-world scenarios and in this paper we describe the sequence of these Phases 1, 2, 3 and 4, which informed the algorithms for software 'A', 'B', 'C' and now 'D'; the software allows architects to address the needs of the visually impaired population.

X.1.1 Phases of Testing

There have been four phases of testing a series of software iterations 'A', 'B', 'C' and 'D'; these tests were used for fine tuning the software for prediction of visibility for vision impaired people. Phases 2, 3 and 4 are discussed here.

2001 to 2003 Phase 1: Briefly extensive testing with 35 people with low vision, in transport hubs, recording the angle, height and distance from 380 objects which informed Software 'A' and identified five factors of interdependent variables. It was a PC based Windows program, published in 2010 by Dalke *et al* and predicted a visibility determining distance line for each VA level. Participants were vision tested for Visual Acuity, Visual Field and colour vision impairment.

2008 Phase 2 test recruited ten volunteers through eSight, with categories of vision impairment (V1 - V10) who self-defined their vision using a visual scale (Grundy *et al*., 1999; Douglas *et al*., 2006; Dalke *et al.,* 2010). Participants were 18+ years with a variety of vision impairment conditions such as Retinitis Pigmentosa, 97% blind with very low field of vision some colour vision, participants with Nystagmus, night blindness, and others having problems with bright light, tunnel vision, cone dystrophy, some sight, light sensitive but relying on rods since birth, peripheral vision only, long sight and reasonable visual acuity

24/60, and another person with wet macular disease. There were no participants from V1, V7 and V9 (V1 has no possible perception of light).

Phase 2 was conducted in a controlled laboratory testing Software 'A' predictions (Dalke *et al*., 2010). Each participant was logged as lowest VA group self-defined that ensured a margin of error for the algorithm. This phase tested distances at which VIPs were able to see the contrast difference between 2187 greyscale patches, presented in three different sized patches of ten grey LRVs on ten grey LRV backgrounds of pre-mixed NCS colours (see Figure X.2); 150mm^2, 300mm^2 and 750mm^2 patches on a 1800mm by 2400mm background, from up to 10 metres distance away were tested (Figure X.1). The LRVs of backgrounds and patches were 5, 10, 21, 27, 40, 53, 62, 71, 82 and 93% LRV positioned randomised at eye level. All greyscales were measured with a spectrophotometer (xyY) and each test conducted in a day lit room; the distance on the grid at which the participant observed the patch was recorded.

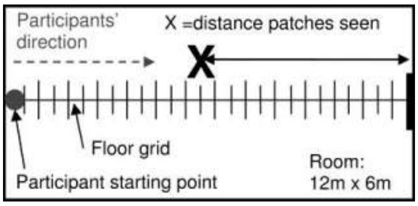


Figure X.1. Diagram of 10m distance testing environment

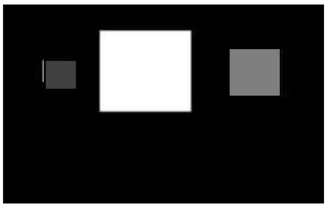


Figure X.2. Three different grey patches on a background

Testing found unacceptable margins of error for small and large objects and the data was used to assess the accuracy of predictions from Software A. Software 'B' was developed – in the form of spread sheet 2D 'lookup' charts with data lines for all contrasts that predicted visibility.

2010 Phase 3: This test in a lab, explored the boundaries of Software 'B'. It extended the data range of the Phase 2**,** with two participants of V4 and V8 and a new test distance was added of 20m. Two extra size patches were tested, 1000mm^2 and 50mm^2 of identical LRVs to Phase 2 which were presented on backgrounds of grey with the increased test course of 20m. Participants observed the patches placed on three 1500mm^2 backgrounds of 5%, 53% and 93% LRV, in randomised sequences (see Figures X.4-5). Each test was in a controlled environment of a Lux level range of 200-400 Lux (see Figure X.3). The distance the patch was observed by the participant on the background was recorded.

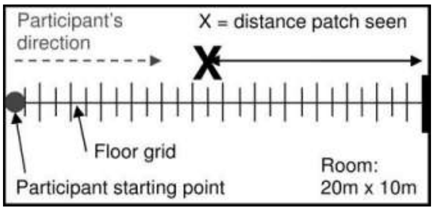


Figure X.3. Diagram of testing environment and course

Figure X.4. 1000mm² patch on 1500mm² background (a). 50mm² patch on 1500mm² background (b).

The results for this phase can be seen (see Figure X. 5a) where a 50mm² object of 90 points of contrast did not achieve better than 5m distance perception for a V4 participant, and a V8 perception improved significantly after 20 points of contrast difference (see Figure X.4).This phase of testing informed Software 'C', a PC based DOS program that encompassed the lookup charts developed in Software 'B'.

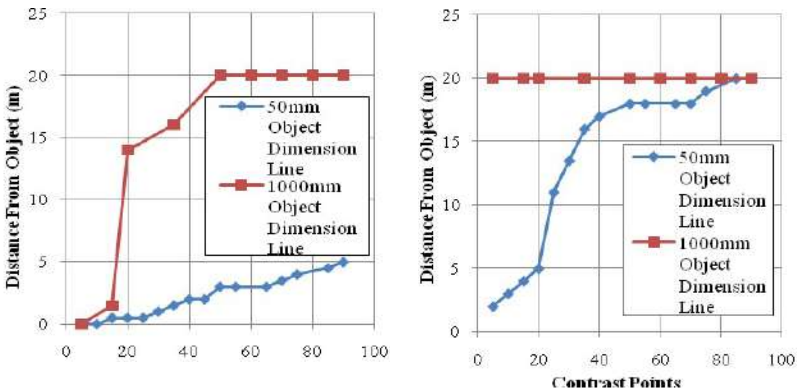


Figure X.5. (a) 50mm and 1000mm Object dimension line and distances seen by V4 participant using results Phase 3. (b) 50mm and 1000mm Object dimension line and distances seen by V8 participant using results Phase 3

2010 Phase 4 used a real-world environment for testing which included variables such as visual noise, and assessed the accuracy of predictions from Software 'C' with six participants V2 to V8. Previous lab tests Phase 2 and Phase 3 had all variables carefully controlled and measured - that is lux levels, dimension, distance and contrast. Phases 4 test was set in an environment with a mix of visual noise and stimuli - The Food Store at Kingston University. The six chosen participants' visual ability was logged as self-defined on the visual acuity scale (Grundy *et al*., 1999) and were V2, V4, V4, V4, V5 and V8 with a V10 control. Five locations were selected for testing. Participants were asked to stand at marked and measured predetermined locations P, established by using the Software 'C'. A list of objects at each location were listed on a record sheet with their data e.g. distance or lux. The following was noted: smallest dimension of the object, LRV difference between object and background, lux level. At location P, the participants were invited to observe the environment in front of them and move forward and 'describe their view'. The target object was not singled out by the researcher; the researcher recorded the distance at which an object # in the environment was clearly perceived by a participant (Figure X.6).

Software 'D' predictions were validated and established the V4+ boundary (V4 to V9 is 93% of VIP) as the software's minimum default. Final tuning of the charts from a comparison of Phase 3 and 4 test results, for the algorithm used in Software 'C, then 'D' was used for an iPhone App, released in November 2010 (www.cromocon.com).

Figure X.6. Walking in the corridor testing distance perception of objects

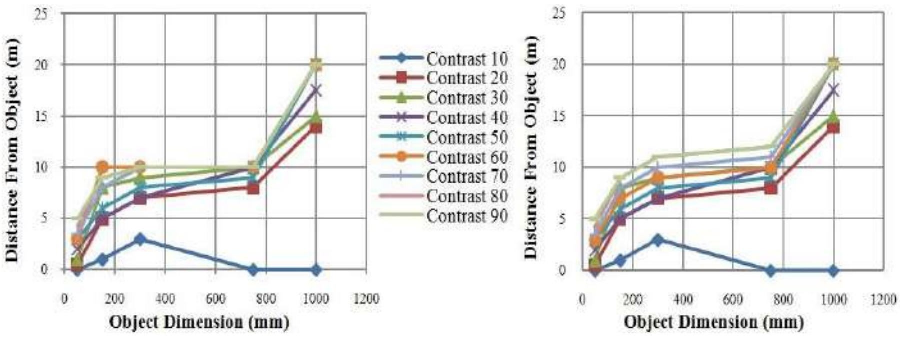
Participants did not score very highly against predictions as most of the tests were conducted below 400 lux, the default level for the software. The sequence of # numbers in the table has some omissions as lux levels could not be controlled and measured accurately, or viewing points were obscured.

X.2 Analysis of Results and Algorithm Development

Previous sections detailed the tests in Phases 2 and 3, obtaining of empirical data, including Phase 4, used to test the predictions of Software 'C' and 'D'. The analysis of the results constructed and evaluated a novel algorithm to predict visibility. A comparison between Phase 2 and 3 results with the predictions from Software ‘A’ showed significant innacuracies to warrant development of further software described in the following sections. A new algorithm was developed using an empirical approach. Results from Phase 2 tests developed Software ‘B’ to overcome the two problems described below.

X.2.1 Extending the Range of the Test Data to 20 Metres

Phase 2 test course of 10 metres was increased to 20 metres for Phase 3 with two participants (V4 and V8). Phase 2 data was extended by ‘typical differences’ where unconstrained data was analysed to identify the differences between object dimension ranges, which were then applied to constrained data. The figure below (X.6) shows before a) and after the adjustments b) for a V4 subject.



a b

Figure X.6. Test results from Phase 2 and 3, participant A05 (V4), for all contrast points. Adjusted test data for participant A05 (V4) extended to range of 20m, for all contrast points.

X.2.2 Adjusting the Data to Normalise for a Constant Lux of 400

A problem with Phase 2 results was optimising the varying lux values between each participant’s tests (from ~200 to ~1000 lux) for a lux of 400, a brightly lit tasked based working environment (Williams, 1999); results from Phases 2 and 3 were rescaled. Lux-distance relationships under different conditions of contrast, object dimension, and the VA level were found using Software ‘A’. Linear approximations to these curves were used to rescale data points. Figure X.7 shows this applied to a sample data point (a).

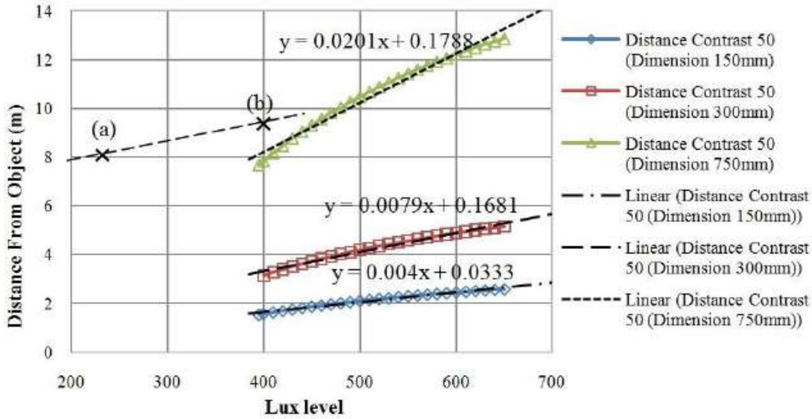


Figure X.7. Lux-Distance lines plotted using data points from Software 'A', V4 Contrast of 50 and Object Dimensions of 150, 300, and 750mm. (a) - Phase 2 Data Point from participant A05 (V4) at Contrast 50, Dimension 300mm, and Lux of 240 (b) - Data point (a) adjusted for Lux, from 240 to 400 using linear trend-line (Distance, Contrast 50, and Dimension 300mm)

The linear approximation depended on conditions of the data point requiring adjustment, including the VA level. Figure X.8 shows results adjusted from 240 to 400 lux can be compared to Figure X.6b for before/after lux adjustment.

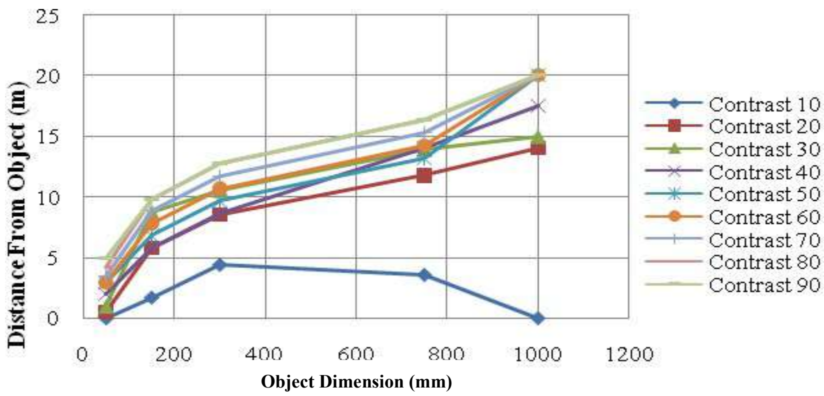
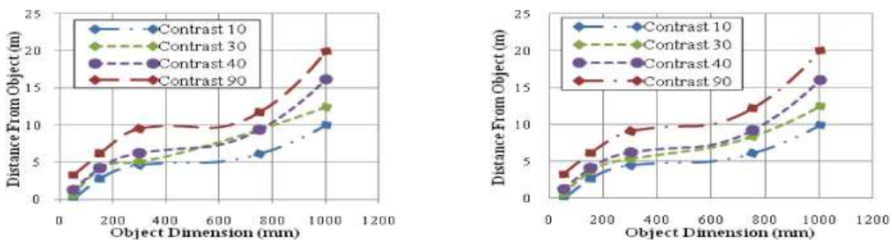


Figure X.8. Results for participant A05(V4) at 150mm,300mm, and 750mm dimensions, adjusted from 240 to 400 lux

In averaging results from Phase 2 & 3 to find a Typical Data Set for Software 'B' we focused on the VA 4 level. Results from Phase 2 and 3 were averaged across all VA levels. A large number of results were used without having to rely on V4 data sets and allowed us to attenuate the visual anomalies to give a better typical visual impairment prediction. The visual range was guaranteed by averaging across VA levels (2+3+6+4+6+3+4+5+8) / 9 = 4.55. Measures of central tendency were investigated with results from Phase 2, a geometric mean was used; extreme anomalous points did not skew these. Central tendency measures were found to have geometric mean that gave the best representation for each contrast data set.

X.2.3 Interpolation between Data Points and Final Adjustments

Linear interpolation is un-representative of a relationship between sight and distance; techniques were investigated such as logarithmic, exponential, and polynomial interpolation. Non-Uniform Rational B-splines avoided the oscillatory nature of previous interpolations as the degree of the curve is fixed independently of the number of points fitting the curve. The interpolation was also extended in the contrast direction creating a NURB surface (Piegl *et al*., 1997) in a 3D visual space consisting of distance, dimension and contrast axes. The surface describes a visual threshold - above the surface signifies no perception, and below, signifies perception. The numbers of data points in the contrast and dimension directions were used as the basis of knot vectors that gave a control net of 5 x 9 points. The Cox-de Boor recursion formula (Piegl *et al*., 1997) was used to define the blending functions in each parametric direction. Figure X.9 shows a sample of interpolated curves superimposed on the same 2D axis.



(a) (b)

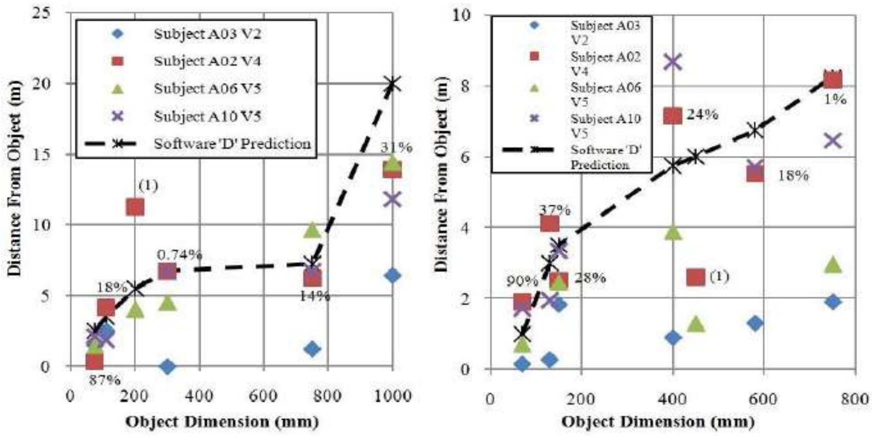
Figure X.9. NURB interpolated curves showing all contrasts for a typical V4 subject (a) and adjusted NURB interpolated contrast curves for a typical V4 subject (b)

Software 'B' was composed of 9 lookup charts in Excel of increasing contrasts from 10 to 90 points. An algorithm was formulated and used these curves developed in a DOS, Software 'C'. These curves were found to contain anomalies (seen in Figure X.9a) where lower contrast lines had higher distances at certain dimensions; these were resolved by lowering original test data points to fit the same behaviour as all other data lines, and by readjusting the control points defining the NURB interpolation between data points. A sample of the revised curves are shown above (Figure X.9b). Software 'C' was adjusted before porting the revised algorithm into the app for the iPhone with a graphical user interface, labelled Software 'D'.

X.2.4 Testing the Software

Tests in Phase 4 (see Figures X.6) and results provided data for comparisons of the predictions of software with participants A02, A06, and A10; A07 and A05 are not compared, as visibility lines were not established with the participants viewing all objects at all distances. All the distances in the Phase 4 tests were normalised for 400 lux.

Contrast 60 and 30 comparisons had the most data points at each contrast stage and represented the majority of the results (See Figure x.10). The V4 subject (A02) in the charts above includes the percentage deviation from predicted, with each data point; apart from points labelled (1) which are considered anomalous. Deviation in both contrasts begins very high with 87% and 90% but these are deceptive if distance differences between A02 and prediction are considered. They are similar at all dimensions except for 1000mm in Figure X.4a. Considering the differences that can exist in visual impairment within the same VA level, subject A02 compares well with the predictions for a typical V4. The two V5 subjects perform lower than the predicted V4, in most of their data points, when they should be higher. Participant A06 (V5) is especially low at contrast 30 point.



(a) **(b)**

Figure X.10. Comparison of Software 'D', typical V4 predictions with Phase 4 test results at contrast 60 points (a) and comparison of Software 'D', typical V4 predictions with Phase 4 test results at contrast 30 points (b)

X.3 Conclusion

The studies highlighted the inconsistency of participants' self defined VA level and the individual eye condition's impact on the observation of targets tested in the 'real-world'. Participants performed worse in busy real-world test locations (Figure X.5) proving the danger of relying solely on lab testing for the development of assistive models of visual perception. However, a secure model has been developed through the investigation of the broad range of variables for perception. Five factors were explored and integrated into a practical tool, the app (www.cromocon.com), which is proving to be a robust and valuable tool for architects in the design of inclusive environments. Further work is being undertaken with a large cohort of visually impaired people to extend the empirical work of the study.

X.6 References

ADA (1991) Americans with Disabilities Act. Accessibility Guidelines for Buildings and Facilities
ANSI/IESNA (2007) Lighting and the visual environment for senior living, IES RP-28-07, New York, US
Barten PGJ (1999) Contrast sensitivity of the human eye and its effects on image quality. SPIE Press, Bellingham, WA, US
Dalke H, Conduit GJ, Conduit B, Cooper R, Corso A, Wyatt DF (2010) A colour contrast assessment system: Design for people with visual impairment. In: Langdon PM *et al.* (eds.) Designing inclusive interactions. Springer, London, UK
Dalke H (2011) The contrast guide. Cromocon, London, UK
DDA (2004) Disability Discrimination Act. Her Majesty's Stationery Office, London.
Douglas G, Corcoran C, Pavey S (2006) Network 1000: opinions and circumstances of VIP people in Great Britain
EHRC (2010) European Human Rights Commission Equality Act. HMSO London
Goldsmith S (1967) Designing for the Disabled. RIBA Publications Ltd, London, UK
Grundy E, Ahlburg D, Ali M, Breeze E, Sloggett A (1999) Disability in Great Britain: results from the 1996/97 disability follow-up to the family resources survey. Technical Report 94. Department of Social Security, Leeds, UK
Harle J, McLannahan H (2008) Visual impairment: A global view. Oxford University Press
Piegl LA, Tiller W (1997) The NURBS book, 2^{nd} edn. Springer-Verlag, New York, US
Pullin G (2009) Design meets disability. MIT Press, Cambridge, MA, US
Rogers-Ramachandran DC, Ramachandran VS (1998) Psychophysical evidence for boundary and surface systems in human vision. Vision Research 38(1): 71-77
Williams W (1999) Footcandles and lux for architectural lighting