NPL Report CETM 42

A Study of the Measurement Requirements within the UK Displays Market Place

National Measurement System Programme for Photonics, Project 3.2 “Developing the Measurement Infrastructure for Standard Display Technologies and Novel Devices”

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1 Executive Summary

This study was based on a survey circulated to 189 people in the UK displays industry, and also numerous conversations with these people. The percentage of responses received was a little disappointing (14%) but similar to previous studies. The conclusions drawn should therefore be taken as an indication of measurement requirements rather than an exhaustive result.

The study highlighted a number of measurement requirements for novel displays, display lifetime prediction and display readability. The key findings are summarised below:

- 58 % of our respondents were unable to make ALL the measurements they required.
- Only 6 % of respondents felt that device data sheets were accurate and reliable
- Uncertainty calculations for display measurement is a source of confusion, guidance in this area may lead to more consistent and accurate quoted uncertainty values. 60 % of survey respondents would like guidance on calculating uncertainties for display measurement.
- The technical terms used to characterise display lifetime terms are not well understood, and the concept of what generates a display "failure" is not clear. Current lifetime prediction methods do not have the confidence of display users or developers; just 13% felt that lifetime predictions were reliable.
- Claims of "daylight readability" do not necessarily yield a readable display, but suggest a display with high luminance 20% felt that a data sheet would indicate if a display was daylight readable. 40% of participants would like an independently verifiable readability metric.
- Very few specific measurements exist for novel displays measurement techniques (e.g. 3D, OLED, projectors). Techniques that allow comparison of newer displays with CRT and LCD technologies would be useful

The survey findings suggest that the most appropriate systems to be developed for novel displays are:

- A system to characterise luminance and chromaticity as a function of angle for novel display materials
- A system to assess the crosstalk of stereo 3D images

60 people attended an open forum held in May 2003 at NPL for display users, where the findings of this survey were discussed. The findings of the survey were upheld and agreed to be representative of the people at the meeting.

2 Introduction and Objectives

The worldwide electronic displays market in 2003 is estimated to be worth $53 Billion, with the European market being $16 Billion, according to Global Industry Analysts Inc "Global Strategic reports" May 2002. This quickly growing market place has rapidly changing measurement requirements and this study aimed to assess the current measurement requirements for novel displays, display lifetime testing and daylight readability of displays within UK Industry.

NPL have received funding from the DTI to develop and construct two new measurement systems for novel displays. This study aims to determine the novel displays requiring new measurement systems. Prior to this study the types of novel displays under considerations were: HMD and near to eye, projectors (including DMD and reflective LCD), 3D, polymer and organic displays.

3 Methodology

This report is based on a paper-based questionnaire and a series of interviews with a cross section of the UK displays community, including display manufacturers, vendors, research companies and university departments throughout the UK. It is not an exhaustive study, but aimed to cover a cross-section of the main users of display in the UK.

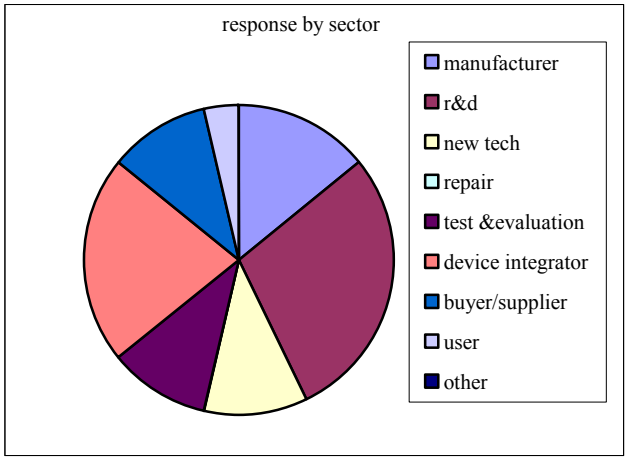
All data was collected in the 3 months between December 2002 and February 2003.

The information presented represents the views of the individuals contacted and may not be representative of the UK displays community as a whole.

4 Survey Results

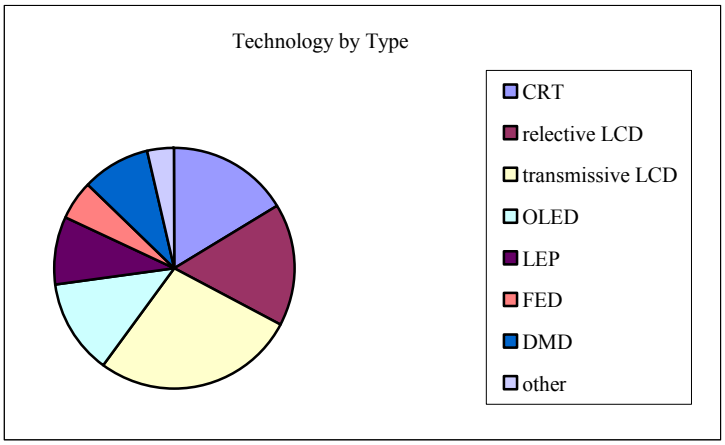
4.1 Company Profiles

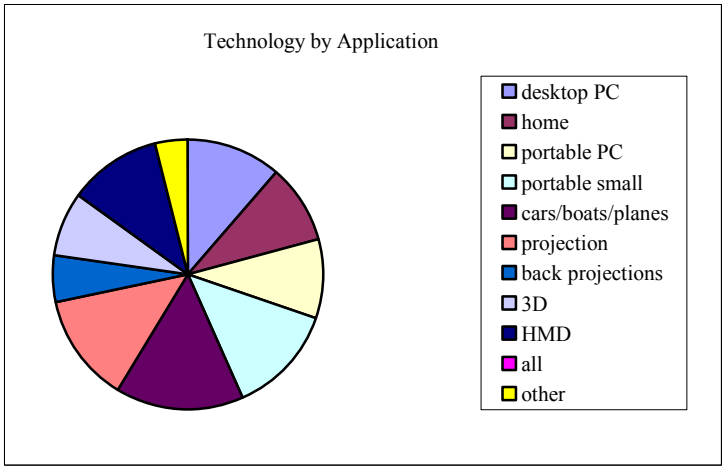
189 surveys were sent out, 30 % were followed up with 14% were completed and returned. 29% of these positive responses classified their main interest as research and development. Device integrators formed the second largest group at 21%, with 14% being manufacturers. The author is aware that the respondents may not be representative of their company as a whole.



4.2 Display Technologies in Use

The types of display technologies used by the respondents to the survey show the UK's display market to be incredibly diverse. CRTs form 16 % of usage, with reflective LCDs at 16 % and Transmissive at 28 %. The remainder of displays used were OLED, FED, DMD and LED.





The display applications that these technologies were being incorporated into were remarkable evenly split, with a huge variety of application sectors represented in this survey. The "others" in this study were ATM machines and displays for medical diagnosis.

4.3 Current Measurement Techniques

Survey respondents were questioned about the current measurements that are made at their premises. All respondents made some measurements of displays, but the uncertainties and traceability of measurements varied widely.

4.3.1 Instruments Used

The institutions questioned used a wide range of instruments listed in order of popularity:
Luminance meter 27 % CCD camera 22 % Spectrophotometer 16 %
Colorimeter/chromameter 16 % Spectroradiometer 12 % Colour Analyser 8 %.

These figures highlight the fact for many display professionals the ability to acquire a result quickly is of paramount importance. A minority of respondents (12 %) used instruments collecting full spectral emission data, implying that luminance and colorimetric data is most commonly required result.

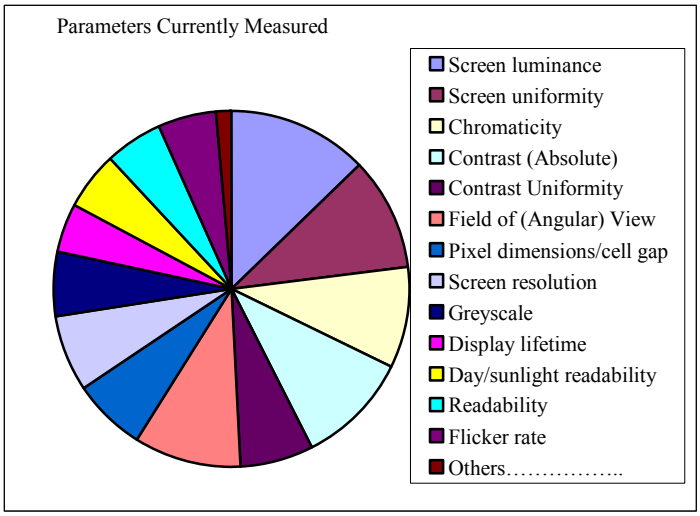
38% of respondents use a modified or home made instrument, this shows that for many users the commercially available instruments are not addressing all of their measurement requirements.

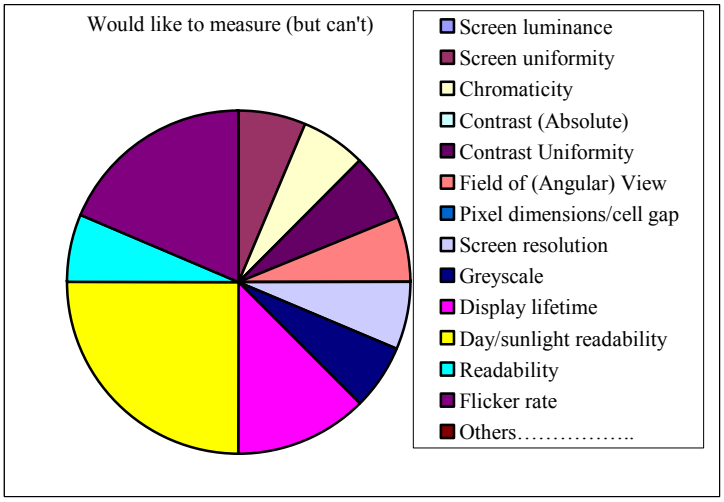
4.3.2 Parameters Measured

Many of the returned surveys showed that respondents were measuring a wide variety of parameters of displays. Most respondents could measure some parameters to a satisfactory

level, while other parameters could not be measured to the level of accuracy required.

The most commonly measured parameter was screen luminance and this was universally measured in candelas per square meter. Chromaticity was measured widely and usually reported in CIE 1931 x, y chromaticities, however some respondents used u v or u' v' as their chromaticity space. Measurements that fell in the "other" category were spectral power distribution and screen gamut.





Several survey respondents highlighted parameters that they wanted to measure, but were currently unable to quantify. Daylight and sunlight readability gave the most problems in measurement, followed by flicker rate and display lifetime. Contrast and contrast uniformity both gave measurement problems as did screen uniformity. The adjacent pie chart shows this for 2D displays, but for 3D display almost all parameters become extremely complex to characterise.

In summarising the results of this part of the survey, one cannot help but feel that the current measurements of displays need some improvement in order to be trusted by display users. Only 6% felt that device data sheets were accurate and reliable, just 13% felt that lifetime predictions were reliable, and a mere 20% felt that a data sheet would indicate if a display was daylight readable. Given these figures and the admission that 58% of our respondents could NOT make all of the measurements that they required, there is certainly plenty of work to be performed in achieving reliable and accurate display measurement

4.3.3 Measurement Uncertainties and Calibration

When asked about the measurement uncertainties they were achieving 35% of respondents didn't know the uncertainty of their measurement results, a further 18% were unhappy with their uncertainties, leaving just under half happy with a uncertainty of the result. 60% would like some help in calculating uncertainty budgets for their measurements.

Most respondents both calibrate their instruments and check that all instruments agree, however significantly 20% of respondents made no checks for inter-instrument agreement, and some noted that although intra instrument agreement was sought, it was not always achieved. This highlights the difficulties of display measurement, and a need for education and guidance on how to assess display measurement uncertainties.

4.4 Display Lifetime Measurements

The survey contained various questions about lifetime measurements for displays; this found that approximately half of our respondents requested lifetime information from suppliers or manufacturers. Of these 71 % requested information based a contractual obligation against their criteria. All of respondents with an interest in lifetime said that the lifetime predictions being used were incorporated as part of the design process. A separate report (Ref Milestone 3.01: Display Lifetimes Literature Search) found that a critical path is missing in display lifetime failure analysis. That is that failure times and failure modes are very rarely fed back to manufacturers. This means that lifetime prediction models cannot be updated to include known failure data, and that display designs are not modified to account for these actual failure modes

4.4.1 Familiarity with Lifetime Terminology

The familiarity with terms used to describe lifetime of components was patchy at best among the survey respondents. Only the term 'mean time between failures' (MTBF) was universally understood, 'mean time to half brightness' (MTHB) was understood by 93% of those questioned. 'Mean time to repair' and 'maintenance free operating period' were widely unknown, with 13% and 20% respectively having never heard of these terms. This highlights a need for education and clarity of these terms. A full explanations of these terms is given in the report (Ref Milestone 3.01: Display Lifetimes Literature Search)

4.4.2 Testing and Failure Modes

When talking about "failure" 63% defined failure as being when the display was no longer fit for purpose. The survey enquired about the types of adverse conditions displays were subjected to, and found that temperature, humidity and vibration were most regularly cited, with shock, electrical fields, high ambient lighting (solar loading), and salt spray also being cited. This illustrates the diversity of applications and environments.

When asked about the most appropriate lifetime prediction models for their displays, 47% preferred accelerated testing, where 24% choose a standard database, and 24% a comparison with similar equipment. This shows awareness within the industry that similar equipment may have very different lifetimes.

4.4.3 Modelling lifetime

When modelling lifetime parameters 55% were using external models and 36% in-house models, 44 % incorporated field trials, with 83% claiming that the model undergoes long-term verification. 78% of respondents say that the technology and environment are included in this lifetime prediction model.

Although these figures look very promising, the truth is that however much verification is occurring only 13% of respondent believe that measurements of predicted display lifetime are accurate, and none of the respondents (0%) feel that these lifetime prediction models are "very good" for analysis of other display components such as fans and backlights.

This is a very disappointing picture of display lifetime prediction

4.5 Display Readability

Participants were asked about readability of displays, in particular they were asked to explain readability, to identify environments where readability can be challenging, and to identify parameters affecting readability.

All definitions of "readability" were subjective but there was a large range of responses, these included phases such as "it must be able to be read without effort", "symbols must be recognisable" and "text must be legible", some respondents also classified this with numbers e.g. "A symbol must be read correctly 97.5% of time by 97.5% of population that will use the display". There were also references made to contrast e.g. "the contrast must be high with the white level similar to surrounding reflected light"

No survey participants gave numerical values relating to optical parameters (e.g. "readability will be achieved for a contrast greater than 20:1") to define readability, this implies that users understand the complex nature of readability, and that readability is a function that is neither well defined nor easily measurable. This was further backed up by the fact that although 73% of respondents said their displays were "more readable than standard displays", 58 % of these people cannot quantify this improved readability. However 40% of participants would like an independently verifiable readability metric

Parameters rated as important to readability were contrast, peak luminance and reflectance. The importance of other parameters (such as daylight readability, MTF, resolution and refresh rate) was not so clearly understood, with a wide variety of responses given.

4.5.1 Daylight readability

Participants were asked to identify the most challenging environments for readability. The overwhelming response was for daylight readability (given as sunshine, outdoor sunlight, outdoors, high ambient illumination and projector in room with ambient light). There were also a significant number of responses identifying nighttime and dusk as difficult environments for readability. Interestingly one respondent included in his definition the caveat "mustn't degrade ability to perform other tasks" this is particularly important when thinking of automotive displays used at night.

It should be noted that claims of "daylight readability" do not necessarily yield a readable display, but often suggest a display with high luminance. Only 20 % of our respondents felt that a data sheet would indicate if a display was daylight readable.

4.5.2 Readability testing

Current tests performed on readability were mainly subjective side-by-side comparisons, however one respondent was using the ORACLE visual model or PJND (perceptible just noticeable difference) where appropriate. There detailed test were performed on whole display systems rather than components and there is a feeling that it would be useful to be able to test one component (such as a contrast enhancing film) as well as the finished product. Some standards are being used including VESA, ISO 9241, and in-house procedures.

Survey respondents would find a metric such as a readability index (or similar) helpful, as 75% of the participants would like to quantify readability, and have independent verification. One suggestion was that a graph of contrast vs. ambient light level given on a data sheet might offer a better guide to readability.

4.6 Novel Display Measurements

Novel display users and developers in the field of 3D, HUD, HMD, reflective LCD, bi-stable LCD, digital cinema, automotive displays, flexible displays and OLEDs responded to our survey. Respondents with an interest in novel displays feel that their novel display offers some benefit to the consumer, whether this is increased contrast, viewing angle, ruggedness or something else, however this is often NOT apparent through current data sheets.

Most respondents were unaware of current measurement standards for their particular type of display (mostly because they don't exist) and all of them would like there to be specific measurement standards for their displays to make the benefits of their novel display immediately apparent to device integrator and potential buyers.

Particular measurements that people would like to see made available for novel displays are shown below:

Novel display	**Measurement required**
3D	Readability in 3D/stereo, crosstalk between stereo images, viewing position.
ATM machines	Ruggedness, reliability, lifetime
Automotive	Contrast with ambient, viewing angle, peak luminance
Bistable LCD	Power consumption, contrast vs. ambient lighting, luminance
Cinema screens	Contrast vs. ambient illumination, luminance vs. angle, contrast uniformity, Modulation Transfer Function & power consumption.
Flexible displays	Luminance and contrast, before, after and during flexing.
HUD and HMDs	Exact measurements not specified
OLEDs	Switching speed.
Reflective displays	Reflectivity, power consumption

The areas of highest demand were:

- Luminance vs. angle for novel light emitting materials, and
- Cross talk in 3D stereo images.

These are the areas identified as requiring new systems to be constructed under our current measurement programme.

5 Conclusions

1) 56 % of our respondents were unable to make ALL the measurements they required.
2) Only 6 % of respondents felt that device data sheets were accurate and reliable.
3) Screen luminance, uniformity and contrast are the most widely measured characteristics. Luminance & chromaticity are required more often than full spectral radiance data.
4) Luminance meters are the most widely used devices followed by CCD cameras. Most instruments are used "off the shelf" without modification, however 38% modify or make their own instruments .
5) Most instruments are calibrated annually (59%).
6) Uncertainty calculations for display measurement is a source of confusion, guidance in this area may lead to more consistent and accurate quoted uncertainty values. 60 % of survey respondents would like guidance on calculating uncertainties for display measurement.
7) The technical terms used to characterise display lifetime terms are not well understood, and the concept of what generates a display "failure" is not clear. 'Mean time to half brightness' is the most commonly used lifetime metric.
8) Current lifetime prediction methods do not have the confidence of display users or developers; just 13% felt that lifetime predictions were reliable.
9) Survey respondents would find a metric such as a readability index helpful. 75% of the participants would like to quantify readability, and have independent verification. High ambient illumination was seen as the biggest challenge to readability.
10) Only 20% felt that a data sheet would indicate if a display was daylight readable.
11) Very few specific measurements exist for novel displays measurement techniques (e.g. 3D, OLED, projectors). Techniques that allow comparison of newer displays with CRT and LCD technologies would be useful.

6 Future work

Novel display technologies have many measurement needs. Measurement techniques will be developed for: Cross talk between 3D stereo images
Colour and luminance change with angle for novel display materials

It should be noted that NPL are already addressing many of the requirements mentioned in this survey. It is rewarding to see that current DTI funded work on display lifetime and display readability is addressing very current measurement needs. This underlines the success of the consultation process undertaking prior to the start of the current photonics research programme. Areas of current research which were re-stated as important in this survey were: Lifetime and reliability testing of displays, Daylight readability (including contrast vs. ambient illumination), and measurement of pulsed display, which will yield information about switching times.

The findings of this survey will be fed into the formulation process for DTI funded NMS research projects. The key issues that will be raised are:

- Continuation of lifetime work
- Continuation of readability work
- Inclusion of best practice guide for uncertainty calculation for display metrology.