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PACS Component: Evaluation of Barco 3 MP LCD Flat-Panel Display

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PACS Component: Evaluation of Barco 3MP LCD Flat-Panel Display

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Contents

Summary

This report gives the results of a technical evaluation of a pair of Barco flat-panel display devices (see Figure 1) intended for use as primary display devices. The devices are greyscale displays suitable for use in diagnostic imaging. They each utilise an Active Matrix Liquid Crystal Display (AMLCD) with a 3 mega-pixel display matrix. The displays were evaluated in combination with a Barco graphics card, recommended by the manufacturer as being appropriate for use with this type of display. The two displays will be referred to as “display A” and “display B” in this report.

The devices were supplied with Barco MediCal software, which is designed to assist in a display device quality assurance programme. The functionality of this software was investigated.

Also included in this report is a general description of liquid crystal display technologies and their role in medical imaging.

A PC owned by PACSnet was used as the base station for testing; the Barco graphics card and calibration software was installed on this PC.

The Barco Coronis 3MP display is a 3 mega-pixel AMLCD thin-film transistor (TFT) flat-panel display. It displays greyscale information only and is targeted at the medical market, for diagnostic imaging use. The screen can be used in two orientations – portrait or landscape – and can easily be rotated between the two.

The screen is sized at 528 mm (20.8”) (diagonal), 2048 x 1536 pixels, with 10-bit resolution per pixel (i.e. 1024 grey levels). It has a maximum quoted brightness of 700 cd m^{-2}. It has a digital video input via a Digital Video Interface (DVI). The display incorporates Barco’s “I-Guard” sensor, which monitors the luminance of the display. The I-Guard sensor is located in the lower right hand corner of the display (when used in portrait configuration) and is permanently attached to the display surround. It measures the luminance of a few pixels under the sensor.

The devices were tested for luminance (consistency, uniformity and variation with viewing angle), contrast resolution, spatial resolution and veiling glare. They were found to perform well under all tests.

Please note that the quality of the reproduced images within this report does not necessarily reflect the quality of the image as seen on the display device itself.

Figure 1. The Barco 3 MP displays

1 An introduction to display device technology

1.1 Liquid Crystal Display (LCD) technology

With the advent of digital imaging systems it has become increasingly common to view medical images on electronic soft-copy display devices rather than film. This has many advantages, not least the cost-saving involved in not printing film and managing its storage. For many years the dominant technology in electronic displays has been the cathode-ray tube (CRT), as it has been in television viewing in the home. Recent years, however, have seen the development of a number of alternative technologies for such small displays, including plasma, liquid crystal and projected displays. This report evaluates a display that uses liquid crystal display technology.

Liquid crystals exist in a state that displays some of the characteristics of a solid (i.e. molecules in the crystal are fixed in orientation within the material) and some of the characteristics of a liquid (i.e. the molecules are free to move around while maintaining that fixed orientation). A substance can exist as a liquid crystal over a relatively narrow temperature range; any higher than this range and it becomes a normal liquid and any lower and it becomes a normal solid. Liquid crystals can exist in several different "phases" displaying different characteristics, and it is a particular instance of one of these phases that is used in liquid crystal displays – the "nematic" phase.

In the nematic state, the liquid crystals are naturally aligned. They can be forced to change their alignment by application of an electrical voltage across the crystal. The degree by which they change alignment can be controlled predictably by the amount of voltage applied. As the alignment changes, the polarisation of any light passing through the crystal is affected in a similarly predictable fashion. It is this property that makes liquid crystals suitable for use in display devices.

Liquid crystals are used in displays by sandwiching them between two layers of glass. On either side of this sandwich are placed two polarising layers. These two layers of polarising material have planes of polarisation that are perpendicular to each other. A backlight is placed on one side of the sandwich and the light from this passes through the first layer of polarising material, causing it to be polarised. The plane of vibration of the light is modified by the liquid crystal according to the alignment of the crystal, which in turn is controlled by the voltage across it. This voltage is applied by electrodes on one side of the liquid crystal cell, hence this particular construction is referred to as 'In-Plane Switching'. Finally, the transmitted light reaches the front polarising layer, and the amount of light allowed through this layer is dependent on the plane of vibration of the light in relation to this second polarising layer. By adjusting the orientation of the molecules, the plane of vibration of the light can be modified and thus the amount of light passing through can be controlled.

1.2 Advantages and disadvantages of LCD technology

Viewing angle

LCDs have a narrower usable viewing angle than CRTs due to the features of the technology used. Luminance and contrast can vary significantly as viewing angle changes. LCD devices should be viewed from directly in front of the display. However, it should be noted that recent advances in LCD technology are significantly increasing the usable viewing angle for such displays.

Refresh rate

The technology used to construct flat-panel displays means that there is no “flicker” apparent to the viewer. However, the screen refresh rate is relatively slow compared to CRT displays and so motion artefact can be apparent with moving or fast-changing images.

Luminance

Flat-panel displays are capable of high luminance and can work well in brightly-lit areas. However, they are often not capable of black levels as low as CRT displays and so often suffer from reduced contrast.

Resolution

The resolution of an LCD display is fixed at the time of manufacture. At the native resolution of the panel the resolution is exact. Should it be required to display images at different resolutions, the image data will need to be rescaled before display. This rescaling can introduce distortion in the displayed image.

Displays using CRT technology, however, can easily be switched between different resolutions without noticeable loss in display quality.

Size and shape

Flat-panel displays are, in general, lighter than CRT displays and have a smaller footprint. Their screens are flat, thus providing a more faithful reproduction of the original captured image.

Power consumption

Flat-panel displays consume less electricity and produce less heat than CRT displays.

Focus/sharpness

Where CRTs require careful focussing to produce the sharpest image, LCDs are perfectly sharp – although consideration must be given to any difference in resolution between image data and the display (see *Resolution,* above).

Geometric distortion

In general there is no geometric distortion with flat-panel LCD displays. If images require to be rescaled for display it is possible that this may introduce minor distortion.

Bad pixels and screen uniformity

LCDs can have “stuck” pixels - pixels which are permanently on or off. Some pixels may be improperly connected to adjoining pixels, rows or columns. Also, the panel may not be uniformly illuminated by the backlight resulting in uneven intensity and shading over the screen. The screen glass itself may also contribute to non-uniformity in the displayed image.

2 Evaluation methodology

The evaluation methodology used was based on the AAPM TG18[1] "Assessment of Display Performance for Medical Imaging Systems" document (draft version 9, October 2002; now published in the final version listed in the References section of this report), with local variation as required. The devices were evaluated in a darkroom. Devices were evaluated as a complete system, i.e. the performance of the display was not separated from the performance of the supplied graphics controller card.

2.1 Tests performed

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4.3 Luminance response

4.4 Luminance uniformity

4.5 Luminance stability

[1] AAPM TG18: American Association of Physicists in Medicine Task Group 18

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4.7 Spatial resolution

4.8 Display noise

4.9 Angular dependency of luminance

4.10 Electronic cross-talk

4.11 Pixel defects

5. Assessment of software performance

5.1 Description of functionality offered

5.2 Testing functionality and ease of use

3 Device description

The supplied display devices were tested attached to a standard PC owned by PACSnet.

Barco supplied a graphics card for use with their displays. This was a BarcoMed 3MP2FH graphics controller, a 10-bit display card with dual outputs. This is the card recommended for use with the 3MP display. The card was installed in the PACSnet PC.

PC make and model: Dell Dimension 8100

Operating System: Windows 2000 Professional v5.00.2195 SP 3

CPU: Pentium 4, 1.5 GHz

RAM: 256 MB

HDD: 74.5 GB

Displays supplied:

Screen A: Name: MFGD3220D

Serial Number: 5271978

Firmware revision v1.08

Screen B: Name: MFGD3220D

Serial Number: 5271962

Firmware revision v1.08

Graphics card supplied:

Product name: Barco 3MP2FH

Driver version: 5.1.11

Resolution: 1536x2048 @ 59Hz

Palette mode: Static grey palette with no system colours

Drawing modes: enable direct draw

Serial number: 2019412

VGA BIOS version: BIOS V1.11.1

Firmware version: V3.05 (14 Aug 2003 09.29.37)

Hardware version: 24

3.1 Physical description of device

Figures quoted are those provided in the manufacturer's literature.

3.1.1. Size, weight

Casing dimensions:

The device has the following dimensions when attached to its stand and in portrait mode:

Height:	590 mm
Width:	385 mm
Depth:	240 mm
Weight:	13 kg

3.1.2 Build quality

The displays were of the quality required for use in the expected environments. There were no reasons apparent that would cause any problems in normal use.

The stand allows for the display to be adjusted for height, tilt and rotation between portrait and landscape orientation.

3.2 Operating conditions

Figures quoted are those provided in the manufacturer's literature.

3.2.1 Temperature and humidity range

Operating conditions:

Temperature: 0 °C to 40 °C

Humidity: 8 % to 80 %

Storage conditions:

Temperature: -20 °C to 60 °C

Humidity: 5 % to 95 %

3.2.2 Fluid resistance

The device was not intended for use in areas where it might be exposed to water or other fluids. Its resistance to ingress of fluids was not tested.

3.2.3 Power supply requirements

Supply requirements:

110/220 V AC, 50 – 60 Hz

Power consumption: 100W max.

3.3 Technical description

Figures quoted are those provided in the manufacturer's literature.

3.3.1 Screen size – diagonal

530 mm (20.8")

3.3.2 Screen size – pixels

Available resolutions:

1280 x 1024, 1200 x 1600, 1536 x 2048

3.3.3 Pixel size and spacing

Pixel size not quoted in the manufacturer's literature.

Quoted pixel pitch: 0.207 mm x 0.207 mm

3.3.4 Refresh rate

60 Hz

4 Assessment of display performance

4.1 Geometric distortion

The display was evaluated for geometric distortions by displaying the TG18-QC test image from the AAPM TG 18 image suite.

In a LCD, pixel positions are fixed and are determined by the position of the individual cells. Therefore, in a properly designed and manufactured display, there should be no geometric distortion apparent. In the display under evaluation there was, as expected, no discernible distortion in the horizontal or vertical direction.

To establish that there was no geometric distortion, a test pattern of squares (AAPM TG18-QC) was displayed and the size of the squares measured.

One square:	21 mm x 21 mm
Two squares:	42 mm x 42 mm
Four squares:	84 mm x 84 mm
Full screen horizontal (20 squares):	420 mm (i.e. 21 mm/square)
Full screen vertical (12 squares):	252 mm (i.e. 21 mm/square)

It was demonstrated that there was no measurable geometric distortion in the displayed test image. No distortion was seen in inspection of any other test images used during the evaluation.

4.2 Display reflections

No formal measurement of the reflectance of the display screen was performed. Subjectively, the display reflectance was similar to other displays in its class.

4.3 Luminance response

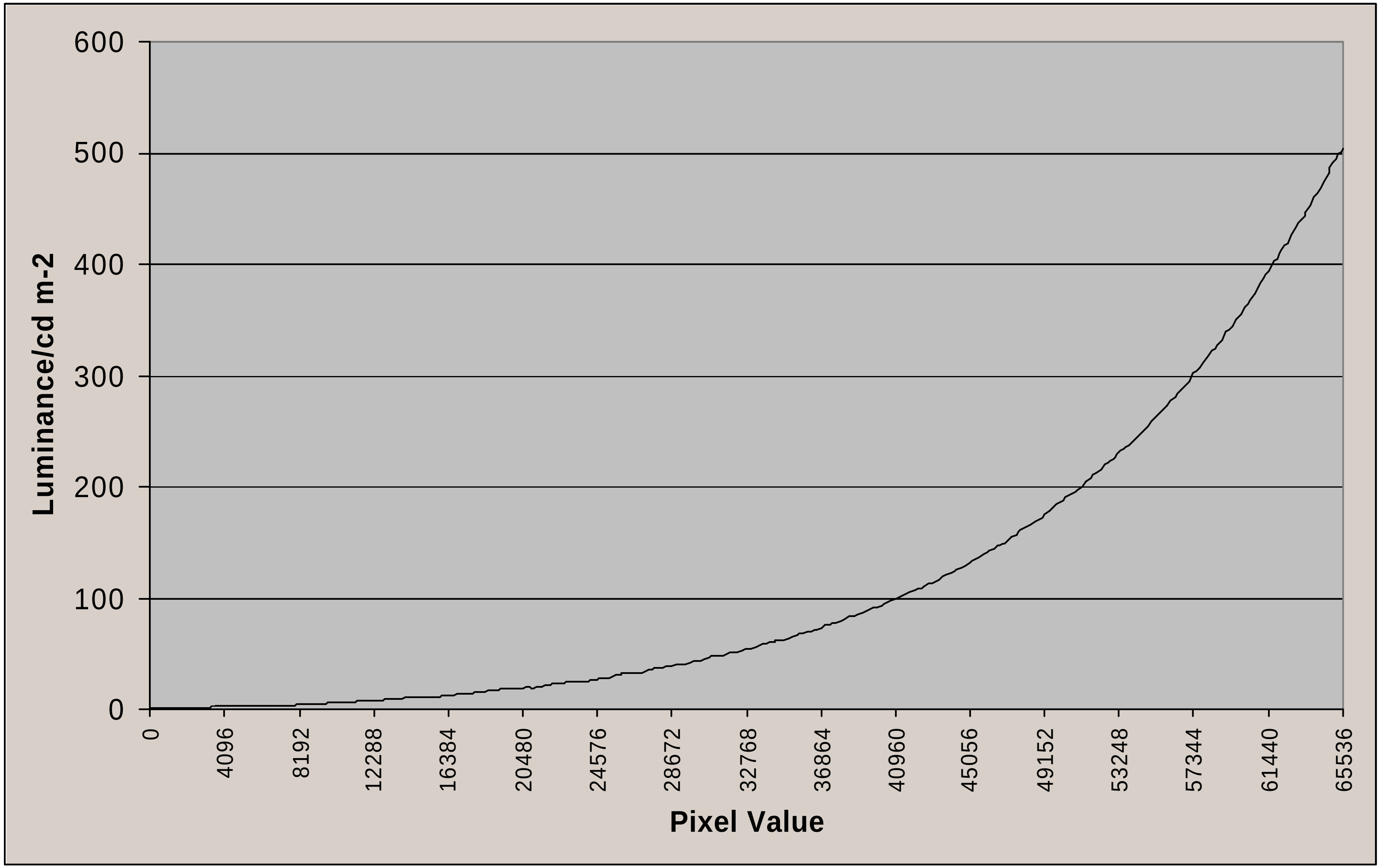
The display was calibrated using the supplied Barco MediCal calibration software. For the purposes of this evaluation, the displays were calibrated to the DICOM Gray Scale Display Function (GSDF) with a maximum luminance of 500 cd m^{-2}. Further information on the calibration software is given in clause 5 of this report.

Figure 2 shows the results of measurement over the complete range of pixel values, using PACSnet's meter to measure the screen luminance.

For clarity, the graph shows the results from only two calibrations and measurements. All DICOM calibration curves produced similar results, the only differences being the value of the peak luminance set.

There is a smooth and steady increase in measured luminance as the image data pixel value increases. The shape of the curve matches that expected for a DICOM GSDF calibration.

Figure 2. Luminance response for DICOM calibration curve



4.4 Luminance uniformity

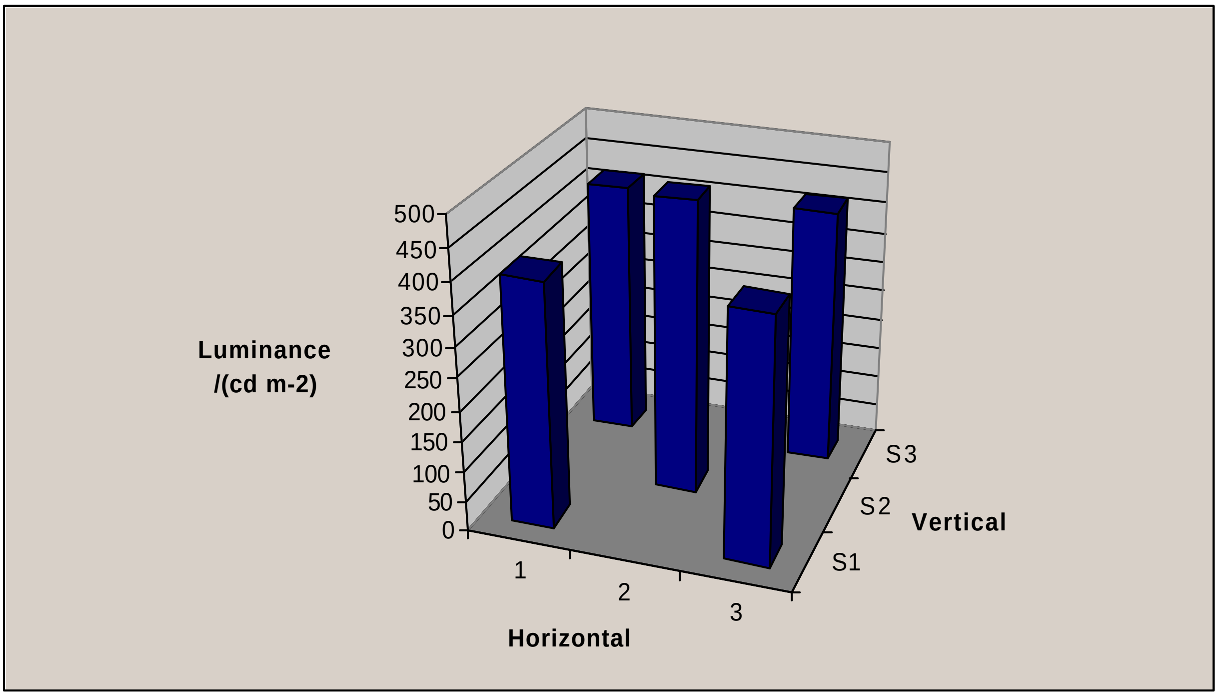
Luminance uniformity was measured by displaying a plain white image over the entire screen and making measurements of the luminance at 5 points over the screen.

Mean results of these measurements (in cd m^{-2}) using PACSnet's luminance meter were:

397.75		397
	475.25	
419.25		417

These results are plotted in Figure 3.

Figure 3. Luminance uniformity



The AAPM TG18 Display Assessment protocol states that the maximum luminance variation should be less than 30%, this luminance variation being calculated by the formula $L_{var} = 200 * (L_{max} - L_{min})/(L_{max} + L_{min})$.

In the above case, the maximum variation is

$L_{var} = 200 * (475.25 - 397)/(475.25+397) = 17.9\ \%$

The luminance variation over the display screen falls below the upper limit of 30% recommended by the AAPM and is therefore acceptable.

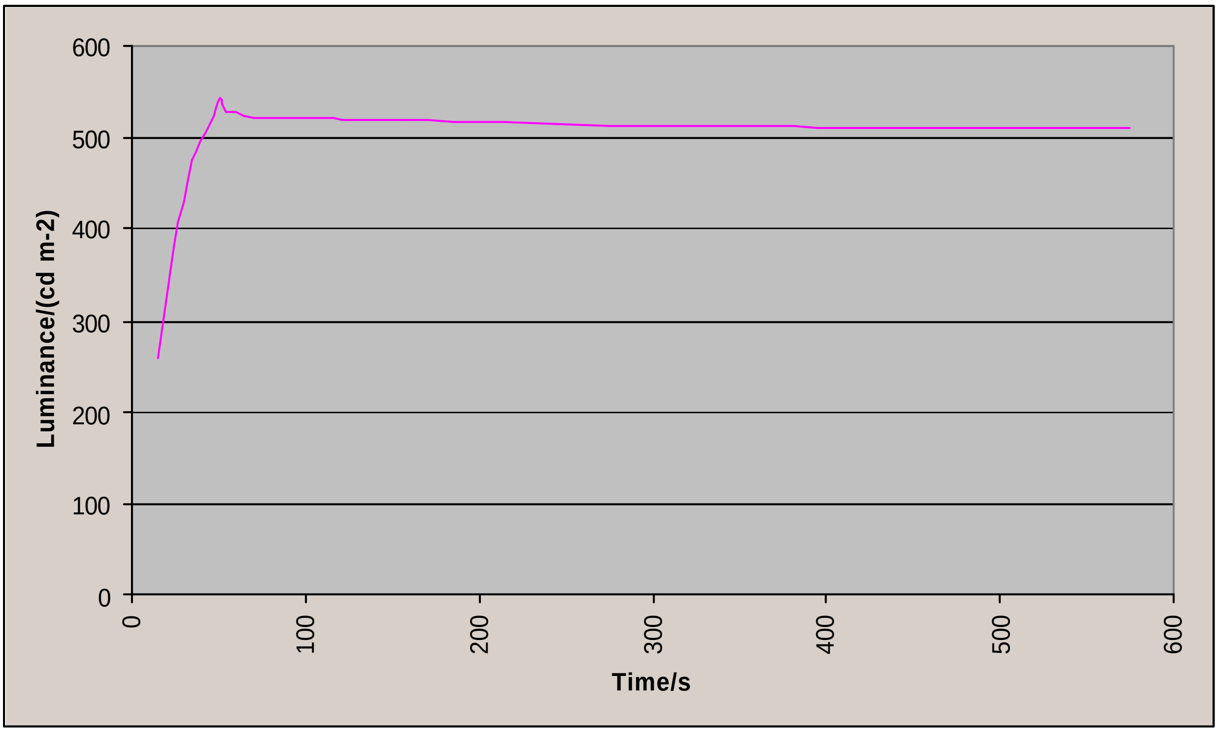
4.5 Luminance stability

The stability of the luminance of the display was measured, both short-term luminance changes following switching on the device and longer-term drift over several hours.

(i) Luminance changes following switching on the device.

To measure the luminance changes here (the “warm-up” time), the system was set up to display a white square at peak luminance at the centre of the display. The display was then powered on and luminance readings taken every few seconds until the display luminance had stabilised. Results are shown in Figure 4.

Figure 4. Warm-up time

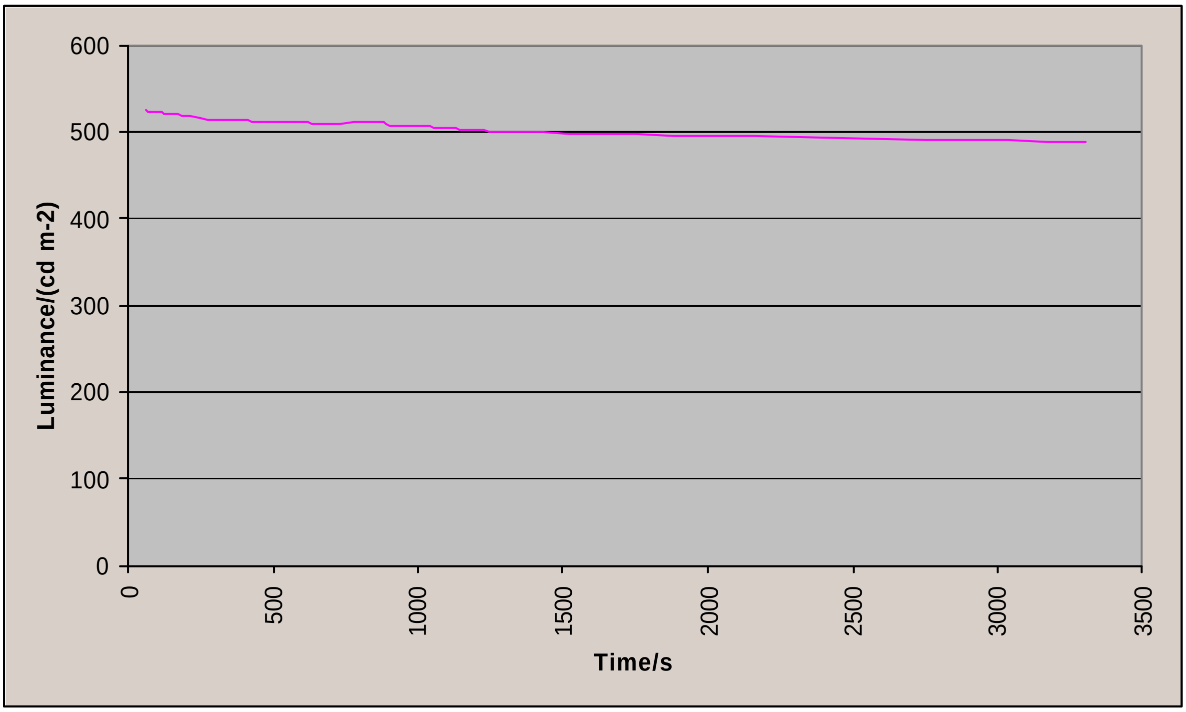


It can be seen that the device reached its target luminance and remained there after approximately one minute. In normal use, this would be well within the time required to start up the base PC and for the user to log in.

(ii) Long-term luminance drift.

To measure any long-term drift in luminance, the display was switched on and displayed a test image in the same manner as for the warm-up measurements above. Measurements were taken for a significantly longer period and the results are shown in Figure 5.

Figure 5. Luminance stability



It can be seen that over the measurement period there was a slight drift in the peak luminance value measured. This drift was not considered to be significant (< 5 % change).

4.6 Contrast ratio

The contrast ratio was measured using the method described by the American National Standards Institute (ANSI). This requires the display of a 4 x 4 “checkerboard” pattern, with eight areas at peak white and eight areas at black. The luminance of each of these areas is measured and the luminance ratio is calculated by dividing the mean luminance of the white areas by the mean luminance of the black areas. The display is masked, apart from an aperture for the area being measured, during this test.

Results:

Mean white luminance: 504 cd m^{-2}

Mean black luminance: 0.75 cd m^{-2}

Calculated contrast ratio: 672:1

The calculated value of 672:1 for the contrast ratio comfortably exceeds the minimum value of 400:1 recommended by ANSI and is therefore acceptable.

4.7 Spatial resolution

The display resolution was evaluated using the AAPM TG18 test image. As expected, the limiting factor for the resolution was the size of the pixels. With test images displayed at 1:1 image pixel:display pixel (i.e. at 1536 x 2048 pixels image size) there was no loss of spatial resolution.

4.8 Display noise

No objective measurement of display noise was possible since this requires use of specialist imaging equipment which was not available at the time of testing.

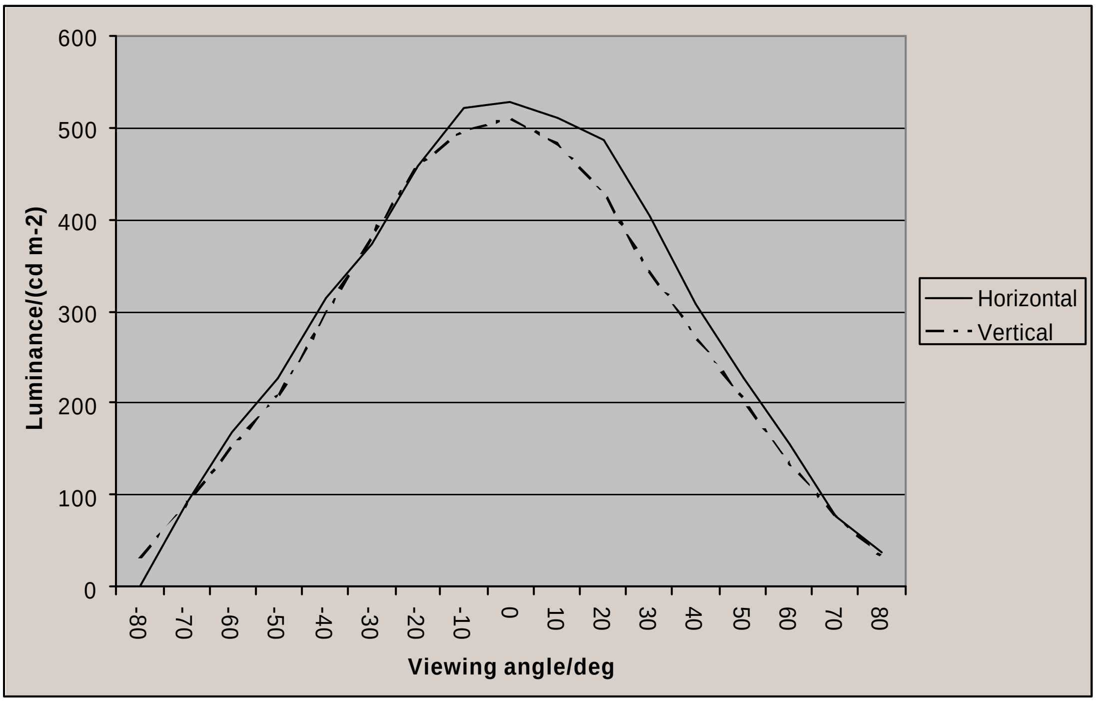
Subjectively, however, noise levels appeared very low and did not interfere with use of the displays.

4.9 Angular dependency of luminance

The apparent brightness of displays can vary considerably with viewing angle. This is especially true for LCD flat-panel displays. This variation of luminance can affect not only the perceived brightness of the displayed image, but also its contrast. The same image viewed from different angles can convey quite different information. This can often be undesirable – for example, two people sat side-by-side looking at the same screen will expect to see the same image – but can sometimes be desirable, for example when personal information is displayed on screens in public areas. In this second case, if the useful viewing angle is very narrow then viewing the information on the screen can be restricted to a person positioned directly in front of the screen only.

Figure 6 shows the variation of measured peak luminance with viewing angle, with the display in portrait orientation.

Figure 6. Horizontal and vertical variation of luminance with viewing angle



4.10 Electronic cross-talk

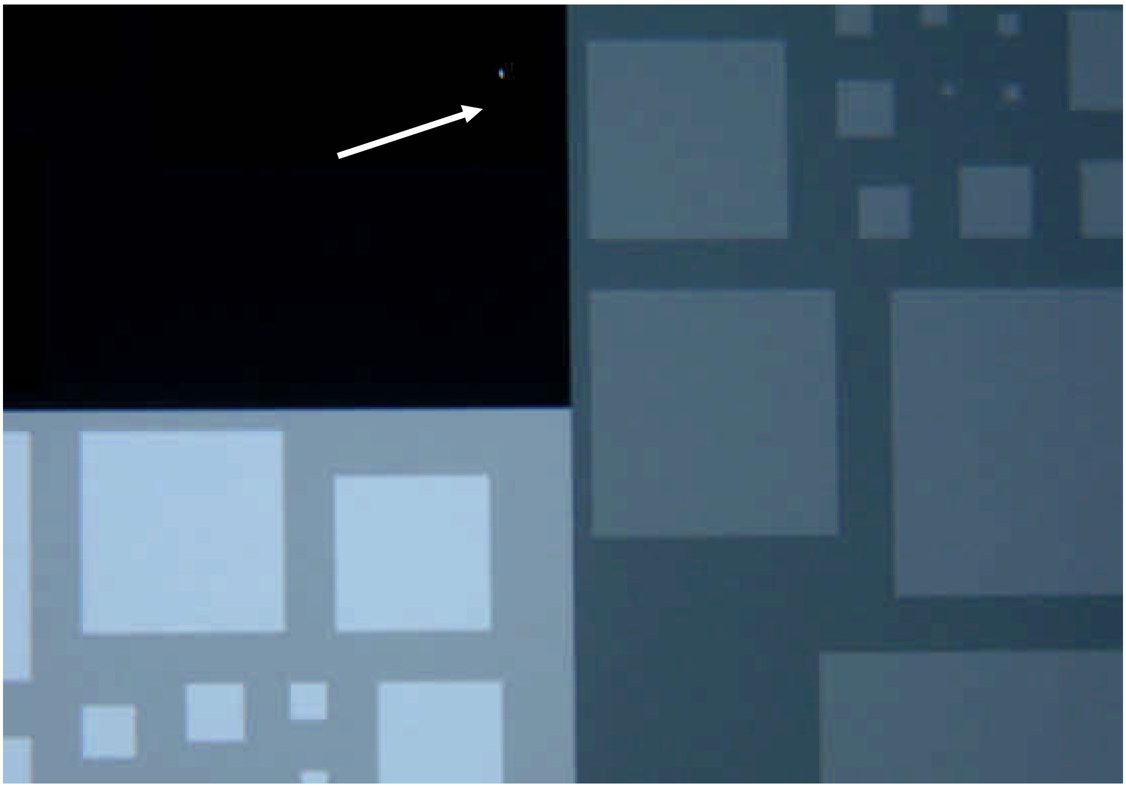
Cross-talk is the unwanted leakage of electronic signal from one channel to another, usually adjacent, channel. In liquid crystal display systems this can lead to the intended luminance of a pixel (i.e. the intended voltage across the liquid crystal cell that forms the pixel) being modified away from the intended value.

There was no effect from cross-talk apparent on a visual inspection of the displayed image.

4.11 Pixel defects

There were two pixel defects apparent to a visual inspection of the displays. These were both on one display (display 'B') and appeared to be "stuck" pixels (i.e. pixels that maintained a fixed luminance irrespective of the actual image pixel value). Such a small number of defective pixels is not considered to be an issue. One of the defective pixels is shown in Figure 7, it is the small white spot towards the top centre of the detail of the screen.

Figure 7. Pixel defect on one display



ISO Standard 13406-2 recommends how many pixels are acceptable in an LCD display. For a 3 MP display the upper limit is 15 defective pixels. The Barco 3 MP display falls well below this limit.

5 Assessment of software performance

5.1 Description of functionality offered

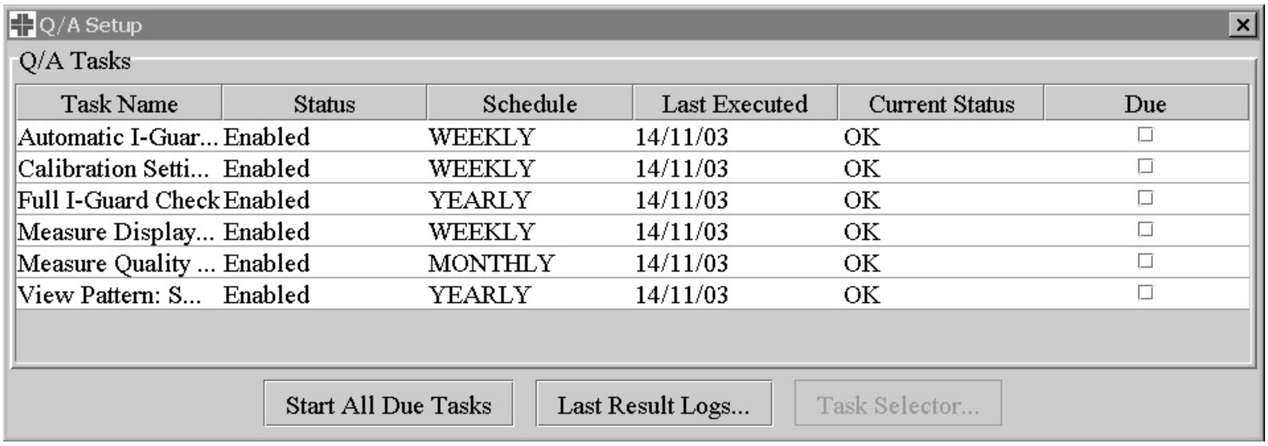
The displays were supplied with the appropriate device driver for the graphics card and with Barco MediCal Quality Assurance software. MediCal allows for the remote calibration of displays and the communication of the results of such calibrations to a central database. Calibrations can be performed automatically at user-defined intervals, with the QA manager being alerted should any displays fall out of calibration.

Installation of the supplied MediCal software was straightforward, as was its use. On first use, the software has no local displays in its database and so asks the user if displays should be added. Following user confirmation, the software searches for (and finds) any attached displays.

For calibration, the user can select the calibration curve to be used (for this evaluation the DICOM Part 14 GSDF was selected), the white luminance level and the black luminance level. Once this has been done, the displays can be calibrated by the MediCal software.

MediCal performs a number of quality assurance checks on the displays, and these can be set to run automatically at user-defined intervals. Figure 8 shows the list of QA tasks available and their schedule.

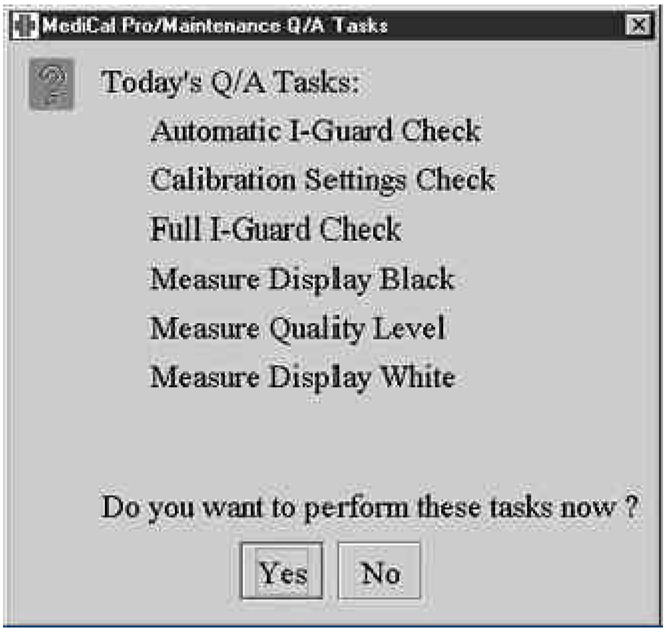
Figure 8. Schedule of quality assurance tasks in MediCal



Task Name	Status	Schedule	Last Executed	Current Status	Due
Automatic I-Guar...	Enabled	WEEKLY	14/11/03	OK	☐
Calibration Setti...	Enabled	WEEKLY	14/11/03	OK	☐
Full I-Guard Check	Enabled	YEARLY	14/11/03	OK	☐
Measure Display...	Enabled	WEEKLY	14/11/03	OK	☐
Measure Quality ...	Enabled	MONTHLY	14/11/03	OK	☐
View Pattern: S...	Enabled	YEARLY	14/11/03	OK	☐

As tasks fall due, users are asked to confirm that they can be run. Figure 9 shows the screen displayed to a user when they first log in on a day when several tasks are due.

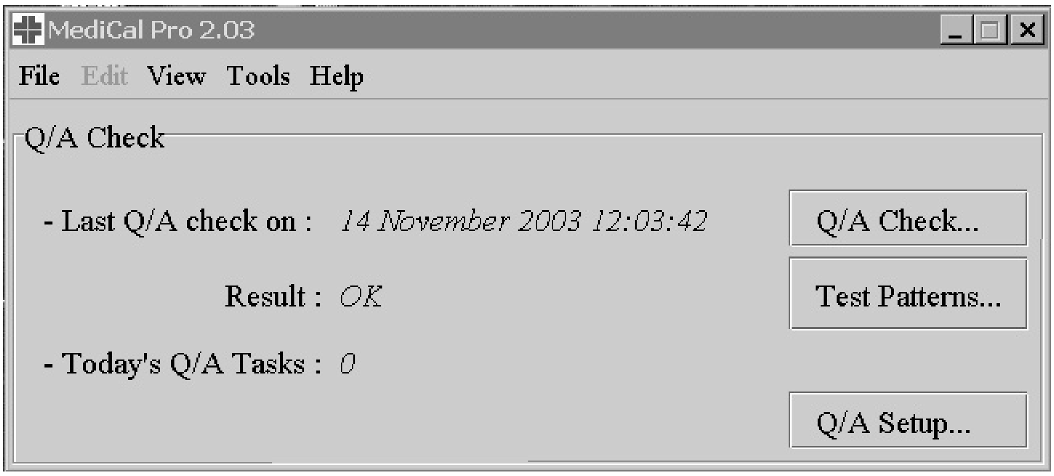
Figure 9. List of quality assurance tasks that are due to be run



The QA setup (Figure 9) allows the user to specify whether tasks should be performed on a daily, weekly, monthly or yearly basis. Full histories for each task are available,

QA tasks can also be run manually. The software informs the user of the date of the last QA check and whether any QA tasks are outstanding via a dialogue window which also allows for QA test to be run, test patterns displayed or the QA checks to be set up – see Figure 10.

Figure 10. Dialogue window for MediCal quality assurance functions

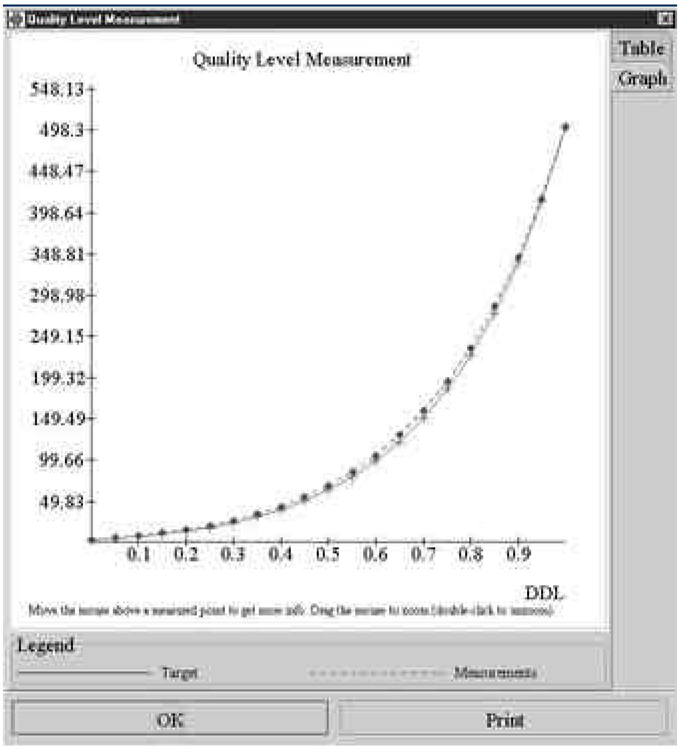


One QA check facility is to measure the "Quality Level". This normalises the input level to the display (the Digital Driving Level, or DDL) and compares the measured luminances for the range of DDLs to the target luminances. Results of these measurements can be displayed as a table (Figure 11) or as a graph (Figure 12).

Figure 11. Results of quality level measurement: table

DDL	Target	Measurements
0.000	1.253	1.082
0.050	2.329	2.195
0.100	3.876	3.752
0.150	6.004	6.038
0.200	8.843	8.895
0.250	12.553	12.917
0.300	17.326	17.676
0.350	23.397	23.192
0.400	31.053	31.796
0.450	40.644	41.175
0.500	52.596	53.107
0.550	67.429	68.086
0.600	85.781	86.348
0.650	108.426	109.085
0.700	136.313	135.962
0.750	170.602	170.872
0.800	212.706	212.571
0.850	264.354	264.912
0.900	327.656	326.878
0.950	405.139	401.812
1.000	500.100	496.580

Figure 12. Results of quality level measurement: graph



In addition, the MediCal Administrator package allows for calibration and QA checks to be performed remotely over a network. Results from QA checks are sent to the Administrator after each execution of the QA application. This functionality could not be tested here

6 Conclusions

The Barco Coronis 3 MP LCD Flat-panel display is a well-manufactured product, with features that make it suitable for use in diagnostic medical imaging, including high contrast ratio, little luminance variation across the screen and good luminance stability over time. As is expected of displays using LCD technology, there is no geometrical distortion in the displayed image.

The display also offers good conformance to the DICOM Part 14 Grayscale Display Function, particularly when used in conjunction with Barco's MediCal calibration software. The QA functionality of the MediCal software was simpe to use and efficient.

7 Acknowledgements

PACSnet would like to thank the assistance of Ivan Boeykens and Peter Adams of Barco during this evaluation.

8 References

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Data Projection Equipment and Large Screen Data Displays -- Test Methods and Performance Characteristics, American National Standards Institute (ANSI) IT7.215-1992, 1992.

9 Bibliography

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Appendix 1: Luminance meter

The luminance meter used in this evaluation was a Hagner S3 Universal Photometer/Radiometer. This is a combined luminance and illuminance meter.

The light sensitive components of the meter are two silicon diodes, each filtered to give a spectral response close to that of the human eye (i.e. the spectral response correlates with the CIE 'standard observer' curve). One of the diodes is internal and is used for the measurement of luminance within a 1º circular field. The second, external, diode is used for the measurement of illuminance and was not used in this evaluation.

The meter is portable. It can be powered by either an internal 9V battery or an external 9-12 V DC power supply. The measurement range of the meter for luminance is 0.01 – 200,000 cd m^{-2}, with a quoted accuracy of ±3 % (±1 in the last digit). Its focussing range is 0.5 m - 8. Polarised light (such as that typically emitted from an LCD flat-panel display) is measured correctly.

The dimensions of the meter are 270 mm x 130 mm x 70 mm. Its weight is 1.4 kg (or 2.0 kg in its carrying case).

Appendix 2: Manufacturer's comments

The following comments have been received from Barco regarding the contents of this report:

The report is in line with the general product perception and customer feedback.

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