**Research on flat panel display measurements at the National Institute of Standards and Technology**

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## ABSTRACT

The National Institute of Standards and Technology (NIST) has initiated a new program on performance measurements for flat panel displays. Prior to this program, NIST completed an assessment of industry needs for measurements and standards to assist in the development of high-resolution displays. As a result of this study, a new laboratory has been established to characterize the electrical and optical performance of flat panel displays. The services of the laboratory will be available to commercial panel manufacturers and users. NIST, as a neutral third party, intends to provide technical assistance in the development of standards and measurement practices for flat panel display characterization.

## 1. INTRODUCTION

The National Institute of Standards and Technology (NIST) has initiated a new technical program to address measurement problems related to flat panel displays. The need for this program was determined partly through an earlier assessment of technical challenges and measurement needs for producing advanced displays. The details and conclusions from that assessment are given in NISTIR 4583, in which we summarize the high and medium technical priorities for manufacturing active matrix liquid crystal, plasma, and electroluminescent displays.[1] These priorities represent major technical challenges and give rise to a number of measurement and standards challenges. Also detailed within the document are some of the measurement needs for incorporating flat panel displays into end-user products.

Our program, within the Electronics and Electrical Engineering Laboratory (EEEL), is concerned with the perceived visual properties of the display and the development of meaningful technical performance standards. The EEEL technical program consists of (1) developing an electronic and colorimetric testing laboratory for completed flat panel displays, (2) acting as an informed source for industry for information related to flat panel display standards activities, and (3) providing technical input to international standards activities.

### 1.1. Related NIST programs

Although not specifically the topic of this paper, there are two other on-going activities at NIST that are related to flat panel displays. To achieve interoperability and flexibility between flat panel displays, and display driving devices it is necessary to develop logical, electrical, and mechanical standards for interfacing computers to flat panel displays. The Advanced Systems Division of the Computer Systems Laboratory at NIST is coordinating efforts to develop voluntary industry standards in this area. Research is also being conducted on the architecture of advanced computer-to-flat panel display interfaces and performance measures for these interfaces.

In addition, the Advanced Technology Program (ATP) at NIST funds precompetitive and generic research in many technologies. Funding decisions are made strictly on a competitive basis through submitted technical and business plans in response to ATP solicitations. The Advanced Technology Program has made several awards that are related directly or indirectly to display technologies.

### 1.2. Why NIST?

NIST is a neutral third party, obtaining no funding from panel manufacturers or users. It can act as a "mediator" when technical disagreements arise. NIST has a history of aggressively pursuing and understanding precision and accuracy in measurements. Internal laboratories at NIST have direct, easy access to the luminance standards for the United States. Finally, NIST is already an active participant in the international standards setting processes.

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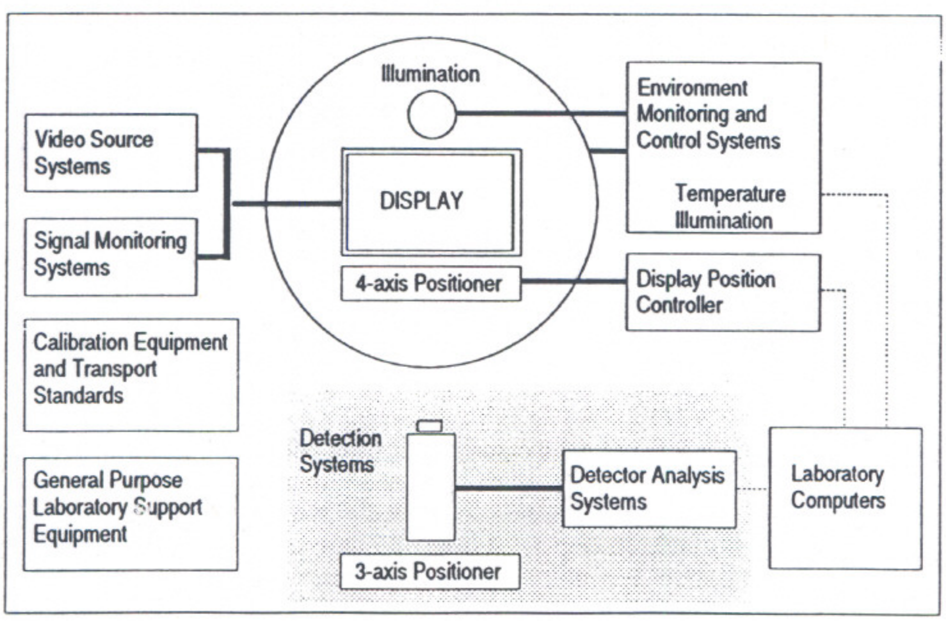
## 2. THE DISPLAY MEASUREMENT LABORATORY

Where possible, we have chosen technical activities that address problems that are independent of a particular type of display technology, as we believe that this provides the greatest benefit to U.S. industry. Consistent with this philosophy, our laboratory is intended to assist industry in developing flat panel display performance measures that are based on sound metrological procedures, and in helping industry develop standard measurement practices that may be later included in international standards.

One of the bigger problems facing the display industry is the problem of identifying which measures accurately predict the performance or quality of a display. There are at present no agreed upon quantitative measurements in the flat panel industry that predict the overall quality of a display. It has been noted to us that in some cases instrumentation is applied to measurements of flat panel performance without assessing the suitability of the instrumentation for that measurement, without defining properly the measurement or measurement environment, or by defining the measurement in terms of a specific measuring instrument. These limitations produce measurements that cannot be reproduced from manufacturer to manufacturer or from manufacturer to user.

In general, we consider objective display performance measures as either (1) related to specific measurable quantities such as gray scale accuracy, colorimetry accuracy, and pixel turn-on and turn-off times, or (2) related to perceived display quality. Some examples of perceived quality that need to be correlated with objective measures include sunlight readability, contrast, ability to discriminate task specific patterns, and overall "quality." The former measurements may be satisfied by a rigorous technical analysis, while the latter require modeling of the human vision system and subjective perception tests. Our initial research will focus on specific measurable quantities while we plan future work to address the more subjective "quality" issues.

The flat panel display measurement laboratory at NIST provides a flexible environment capable of addressing a large variety of display-quality measurements. The laboratory is designed for testing of completed displays, i.e., displays with pixel drivers included. Where possible, we will develop or use technology-neutral colorimetric tests. Tests can be performed on transmissive panels, with and without a backlight; emissive panels; and projection systems. The purpose of the laboratory is to demonstrate "proof-of-concept" measurement practices with only limited production testing of displays expected. Thus in designing the laboratory, we emphasized versatility rather than raw production speed.




Generalized Schematic of the Flat Panel Display Measurement Laboratory

### 2.1. Laboratory apparatus

A generalized schematic of the laboratory is shown in the figure above. Key elements include an automated 4-axis display-positioner within a 1.9 m surround-sphere with controlled illumination and temperature monitoring. Measurement devices include spectroradiometers, colorimeters, and a CCD imager attached to a long distance microscope. Source and test equipment include luminance calibration sources, programmable video signal sources (test generators, computer display adapters, and video tape and disk recorders), video signal monitors, and laboratory computers to control the measurement systems and to log and analyze data. The systems can provide comparative measurements between displays and between pixels within a display. Measurements on local calibrated-luminance standards can relate these measurements to absolute luminance standards.

### 2.2. Laboratory capabilities

The table below lists measurements that are within the capability of the laboratory. Note that many of these measurements may exhibit a temperature dependence and degrade with time.

**Flat Panel Display Laboratory Measurement Capabilities**

- Signal Generation and Measurement
  - programmable video generator
  - programmable video supercomputer for arbitrary spatial and temporal patterns
- Display Environment Monitoring
  - illumination
  - screen surface reflections
  - glare and ambient lighting effects
  - temperature
- Radiometric Characterization of Screen Pixels
  - screen and pixel uniformity
  - angular distribution of radiance and gain
  - color rendering
  - correlated color temperature measurement
  - gray scale
  - crosstalk and diffusion
  - screen resolution and addressability
  - distortion and alignment
- Temporal Effects
  - flicker propensity
  - pixel response and screen update time
  - noise

The measurements enumerated in the table will be performed initially with manual control of the measurement system. This will require that an operator mount a display device and accurately locate and align the optical detectors and perform the required measurements. Complete characterization of a mega-pixel display could require up to several million measurements. Such characterization is impractical without a completely automated measurement system. To provide high measurement throughput while maintaining versatility, we propose to develop a robot system for the automation of the measurements. A robot system may be considered an "intelligent" automated system that adapts to a changing environment, for example, locating and aligning the position of a mounted display, identifying its display surface, and performing the required measurements. Such a system could be a prototype of a display acceptance testing station for use at the end of a display production line.

Display quality issues are not simply a matter of light measurement, power efficiency, display environment, or signal quality. Rather, these factors act in concert with the complexities of human vision perception to affect display quality. Thus, additional research will include an analysis of the visual perception of the eye using a video supercomputer to provide parametric real-time modification to simulated display devices. Models for human vision will be incorporated into the colorimetric results to develop objective measures of display performance that correlate with visual task oriented requirements.

### 2.3. Related supporting services and equipment

Other research divisions at NIST are providing additional technical expertise as needed. Radiometric, photometric, and colorimetric calibrations of laboratory equipment and standards are provided by the Radiometric Physics Division at NIST. Calibrations of the bi-directional reflection distribution function (BRDF) of materials by the Radiometric Physics Division will assist flat panel display laboratory personnel in the characterization of displays in varying ambient light conditions.

The Robot Systems Division has experience in producing robots and associated algorithms to locate and identify test items. We are working with the Robot Systems Division to incorporate a robot system into the measurement process that will allow rapid adaptation to different measurement requirements. This system will have the ability to take efficiently a large number of measurements on individual panels. The flat panel display measurement laboratory has been designed for eventual robot control; all source, measuring, and mechanical positioning equipment are controllable by a computer.

The Video Processing Laboratory (located adjacent to the Flat Panel Display Laboratory) contains the Princeton Engine video supercomputer.[2,3] This massively parallel computer, developed by the David Sarnoff Research Center (Princeton, New Jersey) accepts multiple video signals as input, processes the video information in real-time, and flexibly outputs multiple video signals. The machine has six video inputs and seven video outputs (plug-in cards accept or produce either analog or digital video) with programmable horizontal and vertical scan rates. The Princeton Engine has been used for simulation of display characteristics given analytical or empirical data on display pixel performance. We have used the split screen capability of the Princeton Engine to display "original" video on the left side of a CRT while the same image after simulation processing appears on the right side. We have modeled viewing angle artifacts, crosstalk effects, and phosphor colorimetry for a number of electro-optic displays.

Although program parameters can be controlled in real-time through a networked workstation, we have found it desirable to construct a manual controller with pushbuttons and rotating knobs to input user controlled video signals to the Princeton Engine. This manual controller can be used to modify program parameters as the operator maintains eye contact with the output display device. As part of other research, we have implemented a noise perception threshold test using this controller. A description of this test will illustrate how we plan to use this device for determining other human perception limits. During the noise perception threshold test, the Princeton Engine adds scintillation-type noise to a selected spatial area of an incoming video image. The magnitude of the noise is controlled by the "noise-level" knob. Depressing the "noise-off" pushbutton turns the noise completely off. The test subject adjusts the "noise-level" knob, pressing and releasing the "noise-off" pushbutton, until they are satisfied that the noise is no longer visible. A subject then presses the "show-level" pushbutton to display the numeric value of the noise level on the screen. The ability of the subject to manually control the test produces better measurement reproducibility than adjusting the noise level under programmed control. Similar procedures are planned to determine human perception limits for other display artifacts.

## 3. INTERACTIONS WITH INDUSTRY

The purpose of the laboratory is primarily to assist industry in developing metrologically sound measurement practices and standards for flat panel display devices. Thus interested industry parties are requested to provide input to NIST to identify their measurement needs and suggested measurement procedures. In addition, access to the laboratory is available for testing of user-supplied displays. Measurements can be performed by NIST personnel on a negotiable fee basis with the test results being held confidential. Collaborative research between government and industry researchers may also be conducted on topics of mutual interest. In this case, the full facilities of our laboratory may be made available at no charge to the industry researcher. If the research is of a proprietary nature, a Cooperative Research and Development Agreement (CRADA) may be executed to protect any such proprietary information.

NIST is also developing a list of organizations participating in the development of international and domestic standards related to the performance characteristics of flat panel displays and a list of those standards. This information is expected to be available electronically through access to the Internet. Interested parties are also encouraged to report their activities to help ensure that the data is kept current.

## 4. SUMMARY

NIST has assessed industry needs related to measurement problems for flat panel displays. The details of that assessment have been published and a technical program designed to address some of those needs has been initiated. In particular, a flat panel display measurement laboratory has been created to provide full range performance testing of complete flat panel displays. We will draw on the expertise of other divisions at NIST to relate laboratory luminance standards to absolute luminance units and to develop robot measurement systems. We expect to address future industry needs by extending the existing performance measurements to include elements of the human visual system through modeling and subjective testing using the real-time video supercomputer. Finally, this work is expected to realize accepted measurement procedures and practices that address real industry needs for the measurement of flat panel displays.

## REFERENCES

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