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FOREWARD

"Productivity Through the Application of Theory" is the theme of ISA/78, the International Instrumentation-Automation Conference and Exhibit, Civic Center, Philadelphia, Pennsylvania, October 15 through 19, 1978. The Conference focuses on issues of concern not only to the participants but to our highly technological society, in general.

Contributors to the Conference illustrate the state-of-the-art through clinics, panels, workshops, roundtables, seminars, and tutorials. Particular emphasis is given to the use of computers and minicomputers in the process control industries. Conservation of natural resources, so important for high levels of productivity, are highlighted in discussions of: energy conservation, water treatment and reclamation, air pollution measurement, and pipeline instrumentation. The nuclear industry, lasers, governmental and international standards, as well as process control in general, are all subjects of intense study, discussion, and investigation.

The four parts of *Advances in Instrumentation,* Volume 33, include all available papers presented at the Conference. Seven sessions, presented jointly with JACC/78, the Joint Automatic Control Conference, which, for the first time, is presented in conjunction with ISA's Annual Conference and Exhibit.

These Proceedings are published to highlight and share the fruits of the Conference with all who might benefit. It is our belief that *Advances in Instrumentation,* Volume 33, is important to all involved in the instrumentation fields and to the aims of society at large. These papers can lead to increased productivity throughout the world and to a more judicious use of those resources which all mankind must share.

O. P. Lovett, Jr.
Program Chairman

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Programmed by the following ISA divisions: Process Measurement and Control Systems, Data Handling and Computation.

INTERNATIONAL PURDUE WORKSHOP'S MAN/MACHINE COMMUNICATIONS COMMITTEE ACTIVITY

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ABSTRACT

The International Purdue Workshop on Industrial Computer Systems has many working committees that promote computer control guidelines and standards. The Workshop is made up of representatives of user and vendor companies, university and research institutes that are active in on-line industrial digital computer application field.

TC-6, the Man/Machine Communication Committee, consists of three regional groups: (a) American, (b) European, and (c) Japanese. The American region's major thrust was to produce a document entitled, "Guidelines for the Design of Man/Machine Interfaces for Process Control". This was accomplished at the Fall 1975 International Meeting. This document was revised in June 1976.

This paper will attempt to relate how the development of this document was accomplished by the Committee, the various parts of the document, what international critiques and enhancements are planned, and what other related projects are now under consideration.

INTRODUCTION

The International Purdue Workshop on Industrial Computer Systems came about as the result of a merger in 1973 of the ISA Computer Control Workshop with the former Purdue Workshop on the Standardization of Industrial Computer Languages, also co-sponsored by the ISA. This merger brought together the former workshops' separate emphasis on hardware and software into a stronger emphasis on engineering methods for computer projects. Application interest remains in the use of digital computers to aid in the operation of industrial processes of all types.

This new combined international workshop provides a forum for the exchange of experiences and for the development of guidelines and proposed standards throughout the world.

There are eight committees and these are:

1) TC1 - Fortran
2) TC2 - Industrial Basic
3) TC3 - Long Term Procedural Language
4) TC4 - Problem-Oriented Languages
5) TC5 - Interfaces and Data Transmission
6) TC6 - Man-Machine Communications
7) TC7 - Systems Reliability, Safety and Security
8) TC8 - Real Time Operating Systems

BODY

This paper will be concerned with the TC6 Man/Machine Communications Committee and how the published guidelines evolved.

There have been many types of operator consoles and other types of Man/Machine Interfaces (MMIF) that have arrived at the market place over the last twenty years. Certainly, no one unit services all the needs of industry.

The problem that presented itself within the structure of the Workshop was to see if any proposed standards in the MMIF field should be set. This idea was quickly dropped for many reasons. The technology was changing at such a rapid rate that any proposed standard would be horribly out of date before it could become a standard. A better proposal was to establish guidelines in this area. This idea was accepted by the Workshop and the Committee was turned loose to tackle this proposal.

In order to make sure the Committee was familiar with most of the offering available in this field, several things were done:

a) Started our own bibliography on this subject.
b) Requested vendor literature and demonstrations.
c) Contacted the government agencies, such as NASA, Air Force, Army, Navy and other groups--such as those doing research, etc.

The results of all of the above efforts are documented in the IPW minutes. The Committee was able to visit several of the above installations. This enabled us to see many things not available as yet or not practical for industry. With this type of information now at hand, we were faced with the task of how we could present this knowledge to people not experienced in this field.

There were many false starts attempting to plan a working type document. Fortunately, the group contained very experienced users and vendors. We discussed how many of our own projects had been started, planned and implemented. It appears that each of these projects was handled differently every time, or so it seemed. Several items began to come out of this effort. Although we all knew things happened in certain ways at our own companies, there wasn't a commonality that stood out.

While discussing the lack of a starting basis, someone suggested a top down approach. After this, things began to fall in place. This approach also pinpointed the newer considerations that were being added to the control tasks by government requirements. These regulations eminated from agencies such as EPA, OSHA, NIOSH, DOT, and their related subgroups such as TSCA, CAA, etc.

Other important decisions were then made. These were:

1) To keep the guidelines both process and device independent.
2) Define a model and indicate where the various interfaces occur and how the MMIF is made up.
3) Incorporate Human Factors Engineering into the design. This was not an industry type consideration at the time. This impacts not only the work area, how much a person can control, but also what type person is to perform the tasks.
4) Try to force a good definition of the proposed tasks that were to be performed.
5) Include all four phase requirements (now defined) in the guidelines. These are:

    a) Identify requirements.
    b) Allocate functions among man and machine.
    c) Analyze tasks to perform functions.
    d) Produce functional design.

At this point in time, the proposed document was tentatively laid out in sections. The sections were then broken up and each member was assigned the task of writing his part.

As with all documents, after the rough draft is obtained the editing now becomes a major task. Fortunately, this task was completed to allow the first edition to be printed in October 1975.

There were many suggestions as to the possible changes to be made. During part of the next year, much time was spent making the document more readable and testing it in actual practice. The first revision was printed in June 1976. The title of this document is "Guidelines for the Design of Man/Machine Interfaces for Process Control". This document is available from Purdue Laboratory for Applied Industrial Control, Schools of Engineering, Purdue University, West Lafayette, Indiana 47907.

CONCLUSION

The Committee is now preparing for the second revision. The goals of this revision are:

1) To classify the bibliography by glossary terms and by type of use. This listing should make the bibliography much more useful.
2) Certain portions of the document need to have paragraph headers or some form of identifying the material within the major sections.
3) A better index and table of contents are planned.
4) Continue to make readable wherever possible.

When these revisions are complete, it is hoped that the document will serve the purpose for which it is intended--to enable persons not experienced in the field to be able to put together the proper material to evaluate the products that are now available for use in the MMIF.

ELECTRONIC ARTIST PALETTES FOR MULTICOLOR PROCESS DISPLAYS

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INTRODUCTION

Color CRTs have swept onto center stage—suddenly, it seems—as one of the most noteworthy elements of modern process control systems. Two major technological developments have occurred in the last few years to make their performance excellent and their economics viable. They are: (1) high-resolution color CRT tubes and (2) microprocessor control of their red, green, and blue electron guns.

What is the current state of our art as designers of multicolor CRT displays, and how close are we to fulfilling their considerable promise? Still in our infancy, for two major reasons: (1) we do not have a solid grasp of the electronic and human mechanisms at work in the generation and perception of color on CRTs, and (2) we have been "engineering" and "programming" multicolor displays to a considerably greater extent than we have been applying "artistic" and "human factors" criteria.

A favorable "subjective" response by a process operator to a pleasing display reinforces its "objective" task of presenting information. Hence, display designers must view themselves as "electronic painters" and establish a firm understanding of their medium, their audience, and the interactions between them. The four main elements are (Figure 1):

1) Human color vision and perception
2) The electronic canvas (the color CRT)
3) The electronic palette (color video electronics)
4) The electronic paintbrush (interactive software)

This paper discusses the first three, including a compilation of human factors investigations of the effect of color on human performance in situations applicable to process control. It is interesting to note that little such work has been conducted specifically for process control application, with a few exceptions in the power industry. In general, we are borrowing color CRT technology from the commercial television and aerospace industries and applying it to our needs on a project-by-project basis.

COLOR and HUMAN COLOR VISION

"Electronic" color and "natural" color arise from distinctly different physical processes but have the same effect on the human eye. "Natural" color is "passive"—the result of reflection of incident light from a surface. "Electronic" color is "active"—the result of directly viewing sources of colored light.

Physical objects are "naturally" visible because the human eye is sensitive to the light reflected by their surfaces. Light is electromagnetic energy whose frequencies can be received by the human eye; it constitutes the visible portion of the known frequency spectrum (Figure 2). The natural light incident on a surface (sunlight) contains all these frequencies and is called "white" or "colorless" light. Surfaces have color because they absorb some of the white light's total frequency content and reflect the rest; the reflected portion is "colored light." Hence, an object appears "yellow" because it reflects all the white light incident on it except that in the shaded band in Figure 2B. If color were a characteristic of the object, it would appear yellow regardless of what color light illuminated it (red, white, or otherwise).

On the other hand, when looking at a color CRT our eyes are directly receiving energy emitted from millions of tiny sources of colored light (the red, green, and blue phosphors). Colors are electronically generated by bombarding these phosphors with invisible electromagnetic energy until they are excited to vibrate at frequencies which fall within the visible spectrum. Then they are said to "glow" as sources of colored light.

Color Terminology

"Natural" and "electronic" colors are described technically in slightly different terms. The terms for "natural" (reflected) colored light are (1) brightness, (2) hue, and (3) saturation. Brightness corresponds to the amplitude of the light energy signal, hue to its frequency, and saturation to its waveshape. Brightness measures the "lightness" or "darkness" of the color or the "amount of light" sensed by the eye (not reflected by the surface). Hue is the sensation produced by an awareness of different "wavelengths" of radiant energy and is what we ordinarily mean when we use the word "color." Some colors do not have hue; they are called achromatic (white, black, and all shades of gray). Saturation refers to the sensation that a color is "vivid" or "pale"; it denotes how free from white a color is. White light has zero saturation.

"Electronic" (active) colors are specified in terms of (1) luminance and (2) chrominance. Luminance refers to the intensity of the light source—the amount of light it emits—and corresponds to brightness of natural colors. Chrominance describes everything else about the light and corresponds to hue and saturation taken together.

Human Color Vision

The human eye is a broad-band frequency receiver which responds simultaneously to all radiations it receives within the visible spectrum; it cannot selectively receive light of one wavelength. Thus, if a source of red light and a source of green light are superimposed at the eye, the eye and brain mix them together and interpret the combination as yellow. Hence, actual and perceived colors can be totally different. This is a crucially important point with color CRT displays since we are manipulating light sources—that is, creating mixtures of colored light.

The Eye's Color Sensitivity

A correspondingly important factor is that the human eye is more sensitive to some of the light wavelengths it receives than others. Figure 3 shows the standard curve of human eye response developed by the International Commission on Illumination. It shows that the eye's sensitivity varies with wavelength and that a given amount of light may appear brighter at one wavelength than another. In particular, the eye is most senstitive near the green wavelength of 550 millimicrons and is relatively insensitive to the reds and blues at either end of the visible spectrum. Interestingly enough, the green at peak sensitivity is very close to the green phosphor of a color CRT tube; colors with a large percentage of green will appear noticably brighter than others.

Hue and Brightness Discrimination

The eye can discriminate more changes in brightness than in hue. Brightness resolution is 6 bits and hue resolution is 4 bits, and so the eye can distinguish up to 64 shades of gray but only 16 specifically separated color frequencies. Thus, color CRT displays might best be designed to carry the maximum amount of information with maximum recognition accuracy by using only a few hues with several intensity variations of each. For example, two degrees of alarm severity could be shown as two intensities of red instead of a color change from red and yellow.

Effects of Area on Color Perception

The structure of the human eye causes color perception to change considerably as the size of the colored area changes. When the surface is large enough to fill a substantial portion of an observer's visual field, the brightness, hue, and saturation are substantially uniform. But as the colored surface area decreases, an interesting succession of perceptive deceptions takes place:

1) All colors appear to fall into a range from blue-green, through grays and white, to red-orange;

2) Blues and grays of the same brightness become indistinguishable;

3) Yellows and grays become indistinguishable. Crimsons and browns are confused, as are blues and greens;

4) Blue-greens and grays become indistinguishable;

5) Reds merge with grays of equivalent brightness; and

6) Color perception completely disappears for very small areas and only brightness remains.

These phenomena could be interpreted as demonstrating that everyone is colorblind (to hue and saturation) in certian situations but retains full brightness vision. A color-blind person can get the same information from a color CRT display as a person with full brightness, hue, and saturation vision; he sees a multilevel gray scale with as many brightness variations as there are hues.

Color Mixing

How are colors created? White light can be separated by a prism (Figure 2A) into a limited set of component colors called "spectral colors." All other colors must be created by mixing combinations of these colors. The smallest set of colors which can be mixed to form all others is called the "primary colors." Generally, three primary colors are required. Any three can be selected as primaries as long as two of them cannot be united to form the third.

There are two basic methods of mixing colors: (1) subtractive and (2) additive. The subtractive method is used in color photography and printing. The additive method is used for theatrical stage lighting and color television. The difference between them is that the subtractive method depends on selective absorption (subtraction) of various wavelengths of light by the surface on which the light falls, while the additive method depends on superimposing (adding) two or more light sources of different colors to produce the sensation of a third.

Each method has a specific set of primary colors (Figure 4). The best subtractive primaries are yellow, magenta, and cyan. A cyan filter placed in front of a source of white light absorbs (subtracts) its red component and passes the rest; received by the eyes and interpreted by the brain, the remaining components are interpreted as cyan. Intermediate colors (such as browns) are produced with the subtractive method by varying the relative strengths of the primaries. When all three primaries are superimposed, the result is "black", since all light is absorbed.

The best additive primaries are red, green, and blue. When the light of additive primaries is projected onto a flat, white screen which reflects all of the incident visible energy, the color of the light striking it is reflected unchanged to the eye, where it produces the sensation of corresponding colors. When red and green light are projected at the same area, both are reflected equally and the brain interprets the sensation as yellow. Combinations of red, green, and blue light can produce a wide variety of colors, including the purples and magentas which do not occur in the spectrum. Complementary colors in the additive system are any two which can be united to produce white. Thus, yellow is the complement of blue, magenta of green, and so forth. When all three primaries are superimposed, the result is "white."

The quantities of primary colors required to produce any desired color are known as the tristimulus values of the mixture (Figure 3B). Tristimulus values can be translated into "chromaticity coordinates," which indicate the percentages of each primary required to mix any desired color. The locus of all chromaticity coordinates is called a "chromaticity diagram" (Figure 5A), which represents a map of all possible colors and the relationship of any one to all the others. The curved boundary of this diagram is the locus of all spectral colors—those with the highest possible saturation. The straight portion represents nonspectral colors (the purples and magentas not found in the visible spectrum). Colors are less and less saturated (that is, they contain more and more white light) within these boundaries, until all converge into completely white light at a point called the achromatic point. Light at the achromatic point can be considered to be the color of "daylight." Figure 6 illustrates these parameters.

The phosphors selected for television primaries cannot produce all the colors within the chromaticity diagram. The smaller subset falls with the triangular area shown in Figure 4C, and contains nearly all colors usually found in natural scenes and the costumes, settings, and lighting of television stage productions. Color television can reproduce a wider range of colors than either color photography or four-color printing.

All color CRTs which are economically practical for process control use this set of primary phosphors. Their complete color-miximg capability is not utilized (since the RGB guns are manipulated in discrete digital steps, compared to the continuously variable nature of the broadcast television signal), but, nevertheless, a comprehensive range of chrominance and luminance is achievable without the need for custom phosphors.

COLOR CRT MONITOR (THE ELECTRONIC CANVAS)

The color CRT monitor is the "canvas" in our electronic color painting equipment, and its characteristics are the single most influential ingredient for successful multicolor process control displays. All color CRTs which are practical for process control operate on the same fundamentals, but there are several distinctly different designs currently available, with a wide variation in picture performance. Major variations occur in each of the two main components of a monitor: (1) the electronic chassis and (2) the CRT tube. It is important to recognize the technological and economic importance of properly matching these components with the "electronic artist palette"—the video electronics which the computer manipulates to generate the color picture information. This subject is discussed further in the next section, Color Video Electronics (The Electronic Palette).

The color CRT (like most electronic technology used in process control) is borrowed, this time from the home entertainment industry. The blessings of this "coattail development" are obvious, but successful adoption has stumbled on characteristics arising from accommodating totally different "pictures"—low-resolution, large-area, "scene images" for entertainment, versus high-resolution, small-area, "line drawing" and "textual" displays for process control. Only in the last two to three years have developments been made specifically for our display requirements, namely, the high-resolution shadow-mask picture tube.

Color CRT Monitors

There are three basic types of CRTs, only one of which has acceptable multicolor capability: (1) the storage tube (which has only monochrome capability), (2) the deflection tube (which can show up to four colors), and (3) the raster-scan or television tube (which has true multicolor capability). All CRTs display images as a result of electron bombardment of a luminescent phosphor screen; the phosphors absorb electron energy and glow as light emitters. The storage tube retains the image because its phosphor screen is always slightly energized with a "threshold voltage" so that, once a phosphor is kicked above the glow threshold by the "write" voltage from the electron gun, it continues to glow after the "write" voltage is removed. Two other results are: (1) the storage tube has a constant "background glow" which reduces contrast, and (2) it cannot display color since only one type of phosphor can be used.

The two other types of CRTs are "refresh" tubes; the phosphor glow decays immediately after the electron gun is removed, and so the image must be constantly rewritten (refreshed) fast enough that the eye sees a steady image, that is, faster than the "fusion frequency" of the eye, about 40 to 45 changes per second. At the same time, the refresh rate must be closely matched to the AC line frequency refreshing fluorescent lighting in the control room; even slight differences will cause an apparent movement of the picture, called "flicker." The "beam-deflection" refresh tube has one electron beam which is moved in the same pattern as the desired image on the screen. This tube requires extremely precise and rapid beam control but can draw virtually any shape with whatever resolution is required, anywhere on the screen. Multiple colors are created using "beam-penetration techniques." The phosphor screen consists of layers of different colored phosphors, each of which is excited by a differenct electron beam voltage. Higher voltages pass through (penetrate) "lower voltage" phosphor layers without exciting them. This method of producing color requires very precise voltage control and expensive phosphors. A separate phosphor and voltage are required for each color; the practical limit is three. "Mixtures" cannot be achieved, since only one phosphor can be excited at a time.

The "raster-scan" refresh tube was originally developed to receive television signals and dates to the 1920s. The raster is a rectangular area of the CRT screen within which the image is generated. The electron beam continuously travels across (scans) the raster in a left-to-right, top-to-bottom pattern; the horizontal lines along which it travels are called "scan lines." The beam is turned on and off at many points along each line, creating a pattern of "dots" corresponding to the image. Multicolor raster-scan CRTs were first developed for broadcast television. They utilize three electron beams and a "shadow mask", and have several inherent characteristics which affect picture performance.

Development History of Shadow-Mask Color CRTs

Several attempts were made from the late 1920s to about 1940 to produce color television pictures by interposing rotating red, green, and blue color wheels between the viewer and a monochrome picture. The most successful was called the CBS Field Sequential System (Figure 7), which required several modifications to a black-and-white receiver. It was simple and produced good pictures but had two serious drawbacks: (1) it was not compatible with black-and-white television, requiring greatly increased horizontal and vertical scanning frequencies to produce a stable picture, and (2) screen sizes were inherently small because the mechanical components became cumbersome—the color disk had to be at least twice the diameter of the picture tube.

Nevertheless, nothing better came along, and by the late 1940s it appeared that the CBS system would eventually be the standard. Then in September 1949 RCA launched an all-out program to develop a compatible color picture tube. They started with an unproved idea (the shadow mask) and in six months produced several dozen color tubes with acceptable viewing performance. These tubes used red, green, and blue electron guns and phosphors in a "triad" arrangement (Figure 8). The shadow mask is a perforated metal screen located between the electron guns and the phosphor screen. The holes in the shadow mask are located so that the RGB gun group can strike only those phosphor groups of the same arrangement. The three beams meet (converge) at each opening of the shadow mask. In this early RCA tube the phosphor screen and shadow mask were incorporated into a flat assembly which was then attached to the tube bottle. It was expensive to mass produce and had inadequacies in three major picture performance parameters: (1) brightness, (2) contrast, and (3) convergence or sharpness. (A fourth parameter, resolution, had been adequate from the start for consumer viewing. Resolution capability has significantly increased in the last two to three years, driven by industrial needs, but these high-resolution tubes are not required for entertainment television.)

There have been seven major milestones in the enhancement of these four picture performance parameters:

1) 1953... Curved shadow mask
2) 1965... High-efficiency phosphors
3) 1968... In-line guns
4) 1969... Black-surround faceplate
5) 1970... Wide-angle deflection
6) 1974... Mask-focused tube
7) 1975... High-resolution tube

The curved shadow mask is now constructed integrally with the tube bottle, thus drastically reducing manufacturing costs. It also improves sharpness because all three beams travel the same distance to the mask and phosphor screen.

High-efficiency phosphors (especially red) improve brightness. The low efficiency of the red phosphor had held down total light output emitted by all the phosphors because the excitation levels of green and blue had to be correspondingly low to maintain proper color balance (29%, 58% green, 13% blue).

In-line arrangement of electron guns (versus the triad arrangement) was introduced by RCA and The Sony Corporation of Japan primarily to improve convergence and consequently to improve color accuracy. The three electron guns are arranged side by side in a horizontal plane, eliminating much of the positional variance of the triad arrangement. Phosphors are arranged in vertical "stripes" (Figure 8). Horizontal resolution of these tubes is inherently lower than that of triad tubes. Their shadow masks have slotted holes (rather than round) and thus are generically mechanically weaker. Relatively wide "bars" are required between adjacent "slots" for acceptable rigidity, so phosphor stripes are spaced relatively farther apart than phosphor triads. Also, the image generated by a slot-mask tube is composed of tiny color "rectangles" (compared to the color "dots" of a triad tube) and "edges" of straight lines are noticably more "ragged." Convergence of triad tubes has been improved by better electromechanical design and construction of magnetic focusing systems, by better beam collimation, and by better alignment between beams and the shadow mask.

The black-surround faceplate (Figure 8) has been the biggest single step in improved brightness and contrast; all color television tubes produced today utilize this technique. In earlier tubes the RGB phosphor dots nearly touched to one another, with "empty" interstices, and were purposely made larger than the infringing electron beam to allow for misalignment. Thus, about 60% of the screen was the low-contrast light grayish-tan of the unlit portion of the phosphors and the colorless "empty" interstices. In the blacksurround faceplate the relationships are reversed. Phosphor dots are smaller than the beams and are spaced apart, with the intervening space colored with jet black material. Phosphor spacing compensates for beam misalignment and excess beam energy is absorbed by the black material. Contrast is improved because each colored dot is viewed against black and 60% of the screen area is now black.

Wide angle deflection of the electron guns was motivated by a desire to shorten cabinets but it also improves brightness and sharpness since (1) the electron beams travel a shorter distance and hence lose less energy, and (2) they retain their collimation better and so are smaller when they arrive at the phosphors. Early tubes had up to 90° deflection; current practice is about 120°.

Mask-focusing is a refinement originated by the Hitachi Corporation of Japan, which improves brightness, sharpness, and resolution. The shadow mask is pre-energized so that it absorbs less of the electron beam energy. This condition helps keep the beams collimated to improve sharpness, delivers more energy to the phosphors, and allows finer spacing of the phosphor groups for improved resolution.