Proceedings of the Society of Photo-optical Instrumentation Engineers

Volume 230

Minicomputers and Microprocessors in Optical Systems

Chris L. Koliopoulos, Frederic M. Zweibaum
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Published by
The Society of Photo-Optical Instrumentation Engineers
P.O. Box 10, Bellingham, Washington U.S.A. 98225
206/676-3290

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MINICOMPUTERS AND MICROPROCESSORS IN OPTICAL SYSTEMS

Volume 230

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MINICOMPUTERS AND MICROPROCESSORS IN OPTICAL SYSTEMS

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INTRODUCTION

The rapidly advancing electronics industry is adding a new vitality to the traditionally oriented optics community through the use of minicomputers, microprocessors, and other digital logic. The incorporation of these digital techniques in optical systems has led to increased versatility of control functions, rapid data acquisition and analysis, reduction in cost and complexity, and increased reliability with low maintenance. This technology has already seen its way into a number of commercially available optical instruments. More are sure to come as manufacturers provide increased processing capability to their products.

The papers in this proceedings reflect the beginnings of optics and microprocessors. Where more computing power was needed, minicomputers were used, but it's only a matter of time when microprocessors will have equivalent processing power. Perhaps the most important aspect of these presented papers is the authors' description or philosophy behind the use of a micro/minicomputer in their systems. This proceedings provides the system designer with an overview in the implementation of the various electronic sub-systems within optical systems and instruments. Methods on the optical-electronic interface, how the microprocessor or minicomputer provides control functions, self-calibration, data acquisition, analysis and output display to the end-user are described from several points of view. These papers describe micro/minicomputer systems incorporated into commerical products, laboratory instrumentation, and optical test and evaluation facilities; in each, the system philosophy (trade-offs) can be different.

Even though the seminar which this proceedings documents was separated into four sessions (mainly for continuity and convenience) many of the papers could be equally well described under some other session due to the versatility and similarity of basic functions each computer system provides.

We are at the beginning of a changing era in technology; to be a part of it we must follow. These papers show the initial path.

Chris L. Koliopoulos
Frederic M. Zweibaum

MINICOMPUTERS AND MICROPROCESSORS IN OPTICAL SYSTEMS

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SESSION 1

SPECTROSCOPIC APPLICATIONS

Session Chairman
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Microprocessors in spectroscopic applications of imaging devices: design requirements

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Abstract

The philosophy of design in automating image detectors for use in spectroscopy is dictated by the characteristics of the detectors. The broad range of useful detectors forces general purpose spectroscopic systems to be very flexible. A sample application of imaging detectors is used to present an example of how the devices are used. A multiple box approach was selected to match the above contraints. The detector controllers are preprogrammed state sequences. The computer box in the system was designed on the basis of data word size, data rate, computation requirements, and program support. A specially designed Direct Memory Access (DMA) channel is the key item of the floppy disk/RAM memory microcomputer. The design of the DMA is the key to allowing the detector timing to handle asynchronous events.

Introduction

When considering image detectors and their application to spectroscopy, a number of different detectors are usually considered: film, vidicons, Silicon Photodiode Arrays (SPD's), Charge Coupled Devices (CCD's), and image dissectors. Before a detector is considered useful for spectroscopic applications, it must be examined to determine if certain basic requirements are met. A list of required characteristics is presented in Table 1.

Table 1: Required Characteristics for Spectroscopic Image Detectors

1. Multiple Resolution Elements
2. All Resolution Elements Detect Light Simultaneously
3. Response of Detector Proportional to Incident Light
4. Memory
5. Broad Spectral Coverage
6. "Reasonable" Sensitivity
7. Single Read Out Channel

Film is the classic image detector and it indeed meets all the requirements for the discussion. However, film is a consumable that requires developing. It is also not always convenient to use. Film will therefore be eliminated from the discussion. Image Dissectors do not meet all the requirements. They do not have memory and can therefore only be used as a very flexible single resolution element detector. The CCD detector does meet all the requirements listed to some degree. However, spectroscopists must often work in the UV and commercially available CCD detectors lack this response. They also usually have a very small active area per resolution element putting a strain on their detection capabilities. For these major reasons and other minor reasons CCD's will not be included in this discussion. Therefore, this discussion will center on the vidicon and SPD detectors.

Fig. 1 presents two standard experimental block diagrams used for most spectroscopic applications of image detectors. It is important to note that these applications require a spectrograph. Many spectrometers have a curved image plane not comptaible with the flat face of image detectors. Another major difference can be noted in the transmission experiment. All wavelengths of light are passed through the sample before dispersion. These spectrographs require no scanning mechanism because the total spectrum is dispersed onto the detector.

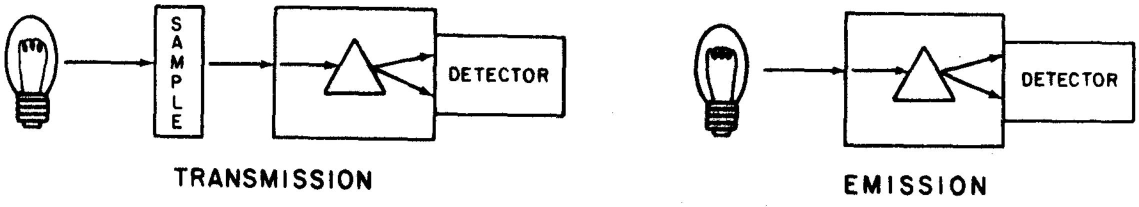


Figure 1. Two common applications of Image Detectors in spectroscopy

Detector Characteristics

The detector shown in Fig. 1 can be either a vidicon or SPD. Before discussing how to control these detectors in an experiment, a brief study of the important characteristics of these detectors is important. Table 2 lists the important characteristics of SPD's.

We use the 512 and 1024 element SPD's with a quartz window or fiber optic bundle in front the array. It is important to note that the 25um spacing of resolution elements falls into the range of commonly used spectrograph entrance slits. The dynamic range was measured by varying both light flux and integration time in order to achieve the range. The great dynamic range coupled with the broad wavelength coverage make these devices useful spectroscopic detectors. The ability to hold the detector temperature very steady gives the rise to very reproducible detector background signals. The important characteristics of vidicon detectors are listed in Table 3.

Table 2: Important Silicon Photodiode Array Characteristics

1. 128, 512, 1024 Resolution Elements
2. 180 to 1100nm Spectral Coverage
3. 25 μ by 2.5mm Element Size
4. Dynamic Range Approximately 400,000
5. Fixed Geometry
6. All Signal Read in Non Overload Operation
7. "Graceful" Overload
8. Rapid Read Speed
9. Easily Cooled

Table 3: Important Vidicon Characteristics

1. Read Beam Approximately 25 μm in Diameter
2. Dynamic Range of > 50,000
3. Two Dimensional Resolution
4. 200 - 800nm Spectral Coverage
5. Significant Dark Durrent
6. Difficult to Cool

When designing a controller for this detector the two most dominant features in the discussion are the two dimensionality and dark signal. Dark signal can be reduced to nil by cooling the detector but it is difficult to cool this type of detector as the active parts are inside a large vacuum bottle. Therefore, any device controller must be designed to handle dark signal at room temperature. The two dimensionally controlled read out beam provides great flexibility allowing the detector scan format to be adjusted to match the experiment. However, to take advantage of the flexibility, a large amount of detector control is needed.

All of the previous discussion is based upon the characteristics of non-intensified detectors. Both vidicons and SPD's can be intensified, greatly increasing the sensitivity of the detector. Fig. 2 depicts a number of ways that this intensification can be accomplished.

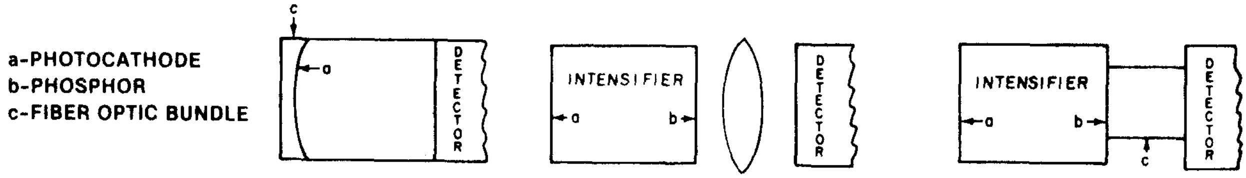


Figure 2: Common modes of Intensification

These intensified detectors must now rely on a photocathode which limits the spectral coverage of the detector. However, photocathodes may be optimized to perform best in particular regions of the spectrum. Besides the large increase in sensitivity; intensification adds gateability to the capabilities of the detector. It is now possible to have an accurately controlled electronic shutter that can be turned on and off in times down to 5ns.

Table 4 lists a group of detectors with some of their important characteristics. The table is presented to generate the awareness that there is no pertect detector. For any given task one particular detector is more appropriate then another. Therefore, a flexible instrument system will have to be able to handle all possible cases.

Table 4: Detector Comparison

	Vidicon	Diode Array	Intensified Vidicon	Intensified Diode Array	Doubly Intensified Vidicon
Dimensions	2	1	2	1	2
Gated	NO	NO	YES	YES	YES
X Axis	500	1024	500	approx. 700	500
Photons/Count	1850	2000	20	10	10
Cost with Controller	X	1.2X	1.4X	1.9X	2.15X

System Approach

Any detector system based upon imaging detectors must have the flexibility to work with any of the detectors that have just been listed. The system depicted in Fig. 3 is an attempt to meet the flexibility requirements.

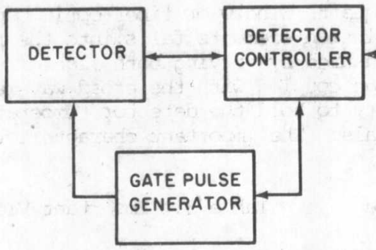


Figure 3: System Block Diagram

Addressing the detector, the most important box, first. Table 5 lists the major reasons for keeping the detector in a separate box. Detector size (and weight) are important. Many times it is very difficult to find the space required to place a detector into an experimental setup. Thus, the smaller the detection box, the better. Electrical shielding is another concern that dictates a metal case around the detector and its sensitive preamplifiers. If the detector controller does not contain the detector, it does not have to be designed to handle all types of detectors (ie. 512, 1024, intensified). Also, this approach does not require a mechanical redesign of the controller if a new detector is added to the system.

SPD's and Vidicons require totally different control and their controllers must be different units. Once this decision is made, each box should be computer controllable. The computer control requirement will become obvious when the computation, data rate, and control requirements are addressed. Because detectors (especially vidicons) require many careful adjustments that vary from detector to detector, a separate, removable, alignment card is used. The detector controller inputs and data outputs are transferred on both a parallel I/O port and an opto-isolated current loop. The opto-isolated current loop allows the detector controller to be located at a large distance from the main controller and work in electrically noisy environments. It should be noted that the bit rate on the serial line is 4MHZ. The common serial transmission scheme, RS232C, is too slow to handle the data rate.

Table 5: Reasons for separate Detector

1. Size
2. Weight
3. Multiple Detector Types
4. Shielding

Table 6: General Detector Controller characteristics

1. One Box For Each Detector Class
2. Removable Alignment Card
3. State Sequencer
4. Computer Controllable
   a. Serial I/O
   b. Parallel I/O

Control of Vidicons

The major thrust of controller design for vidicons was to have the ability to match the detector to the experiment. A spectrograph slit has a definite height; so a ΔY control is added Xo and Yo control. Because optimum resolution is desired the scan pattern shown in Fig. 4 is used. This pattern matches the slit image of a spectrograph. The dotted lines indicate beam blanking which lasts for approximately 5 μsec. The time allowed to scan a line is variable but the blanking time is always the same.

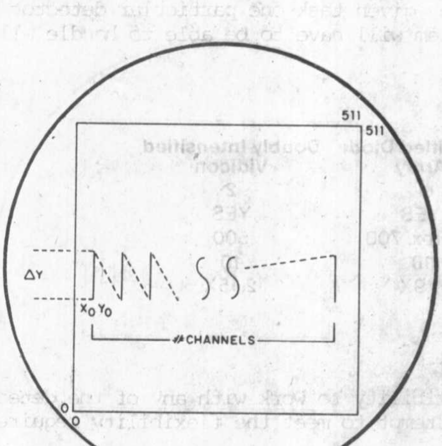


Figure 4: Vidicon Read Beam Control

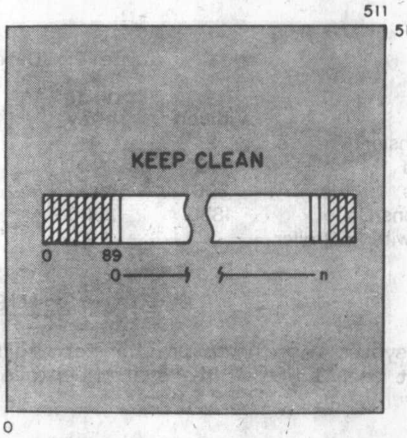


Figure 5: Single Track Scan

When the target is being scanned in a contracted pattern,the remaining target will saturate due to dark current. This saturation will "bleed" into the scanned area and must be considered. To avoid this problem, 3 channels on each end are read and ignored. The bleed into the top and bottom of a channel is small and can be subtracted by doing a background subtraction. (The subtraction of a stored curve that had been run under identical but non illuminated conditions).

A second scan problem is hystersis in the deflection coils. When the read beam is directed to move a long distance over the face of the detector, it never quite reaches the desired point due to the deflecting coils "remembering" their last position. On a full screen deflection this hystersis can be up to 2 channels in X. To overcome this problem a total of nine channels are read and ignored at the beginning of a track. This allows enough time for the deflection to linearize. The X asix is always scanned with 9 channels in the front and 3 channels in the back read and ignored. Fig. 5 presents a typical single track scan pattern. The KEEP CLEAN area is scanned at all times but those when data is acquired. The use of such a KEEP CLEAN approach prevents a scan pattern from "burning" into the detector.

As just intimated, the two dimensional character of the vidicon allows the user to think of many possible scan patterns more complex than that in Fig. 5. Fig. 6 presents some possible scan patterns that might be used. These patterns require that the detector controller remembers a series of Xo, Yo, ΔY values for each track. The optimum scan rate for a vidicon has been shown to be 60 to 80 μs/channel. At this rate there is not enough time for a computer to control all the things that need control and still input data. Therefore, the detector controller is totally preprogrammed before the experiment. This approach frees the computer to do nothing but input the data during an experiment. In multiple track operation it could be possible to have a separate X axis memory loaded for each track. This requirement would demand much memory that would not be used by all experimenters. Therefore the design limit of only one X axis control pattern was applied to the vidicon detector controller.

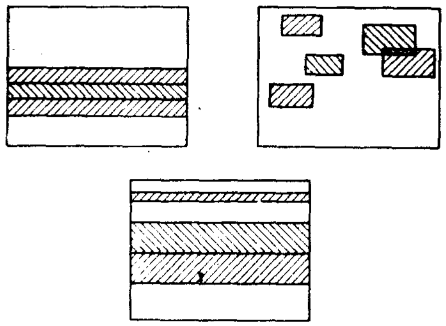


Figure 6: Possible Multitrack Scans

Control of SPD's

These devices are much easier than Vidicons to control. They are linear, taking a start pulse and a clock pulse for each light sensitive element (pixel) being scanned. Each pixel must be read in order before the scan of the device may be restarted. Living within this limitation, the scan options listed in Table 7 still present themselves.

Grouping is the first mode that might not be obvious. The sensitivity or gain of the detector system is defined by the charge read from a pixel imposed on the capacitance of video output line. If two pixels are "dumped" onto the video line, the sensitivity of the detector can be increased on a per data point basis. Of course, fewer data points (lower spectral resolution) is a complimentary result of grouping. Fast access allows the diode array to be clocked at the rate of .5 μs per pixel. The data from these pixels is lost but it is possible to speed up the reading rate of the array in this fashion. The detector is fast accessed up to the region of interest and returned to normal for that region. Better time resolution of an experiment can be obtained utilizing this mode.

The use of delay frames goes hand in hand with thermoelectric cooling of the detector. When cooled the detector can integrate light for 10's of seconds before suffering from appreciable interference due to dark current. The ability to integrate light for a long time before going through only one electrical read out (with its associated noise) greatly enhances the effective sensitivity of the detector. The advantages gained from thermoelectric cooling are listed in Table 8.

Table 7: Diode Array Scan Modes

1. Normal: Read All Pixels
2. Dummy: Read But Ignore Some Pixels
3. Group: Adjacent Pixels Made Into One Data Point
4. Fast Access: Clock But Don't Read Some Pixels
5. Delay Frames: Control Exposure Time

Table 8: Performance Gain Through Cooling

1. Reproducible Background
2. Low Dark Current
   a. Large Signal Range
   b. Long Integration Time

Experimental example

Before examing the design philosophy of the computer box that is the last box of the system, a look at an application of a vidicon detector will help in gaining an understanding of some of the computer box design constraints. An experiment was set up to examine the spectral output of a Xenon flash lamp. When monitored with a pin diode, the output versus time is shown in Fig. 7. Fig. 8 shows the λ output of the flash when examined by a vidicon mounted onto a spectrograph.

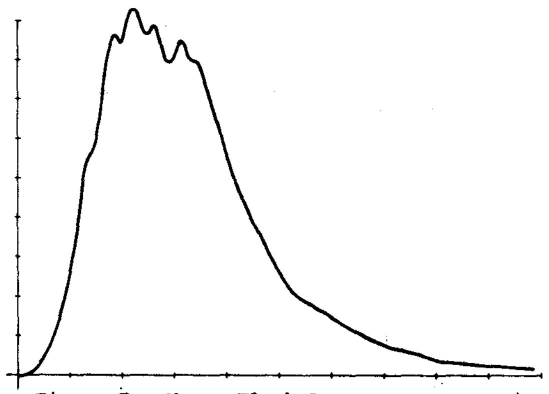


Figure 7: Xenon Flash Lamp output vs. time 500 USEC duration

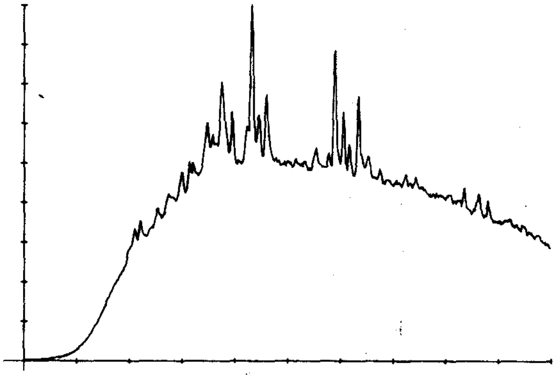


Figure 8: Xenon Flash 5ØØ USEC duration 36Ø - 64Ø NM

In this experiment the flash was triggered in the 9 ignored channels at the beginning of an X axis scan and it was completed before the first light sensitive element was read. There is much more time resolved information available than that provided by Fig. 8. Figure 9 is the spectral output of 50 μs time slices that start at 0 and 50 μs after the beginning of the flash. Note that the inital light output is mostly spectral lines. The continum output takes some time to begin.

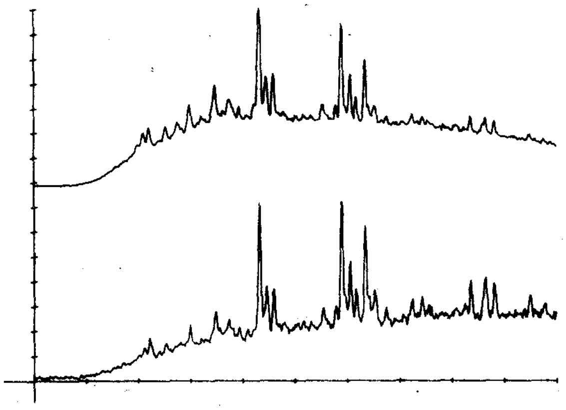


Figure 9: Xenon Flash Lamp: 360-640nm: Bottom Trace 0-50 μs 100 cnts Full Scale
Top Trace 50-100 μs 7200 cnts Full Scale

This "time slice" gating can be carried one step further. By using the experimental setup in Fig. 10, the complete spectral output versus time can be measured using only one flash. This experimental setup is used to transform the Y axis of the detector into time. The effect of the two slits (one fixed the other moving) is to image the spectrum of the output of the source on different Y axis slices at different times. Therefore, time zero can be considered to be centered about Y=Ø and time ? (depending on chopper rotation rate) centered at Y=400. Fig. 11 presents two possible ways to read the signal presented to a vidicon. The first scan pattern gives little wavelength resolution but excellent time resolution. Fig. 12 presents the data obtained from this scan pattern when a zero order image of the flash is studied. The match of this data to that obtained by the single diode is obvious. However, it is the use of the second scan pattern with its poorer time resolution but excellent wavelength resolution that yields the interesting data presented in Fig. 13.

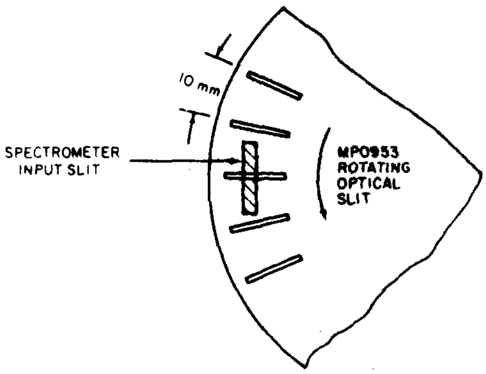
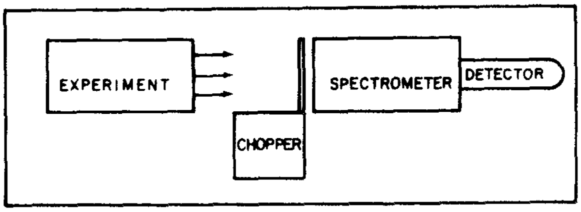


Figure 10: Chopper-Spectrometer relationship



Typical experiment

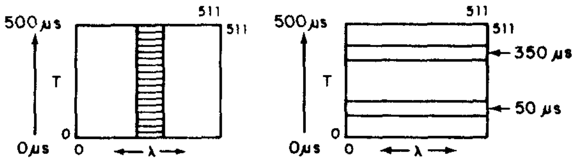


Figure 11: Multitrack Scans of moving Slit Image

The data is plotted with each track shown side by side. However, the data is available to study in the same manner as that presented in Fig. 9.

The important thing to recognize here is the large number of data points involved in an experiment such as this. It is also important to realize that data manipulation must be done on whole curves, as full spectrum are being studied. Therefore the computer box must be a fairly fast curve processor besides having the ability to handle the data rates (16 bits every 16μs) from fast detector electronics.

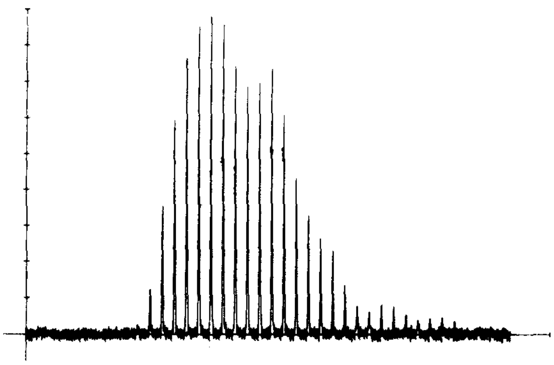


Figure 12: Xenon Flash Lamp Zero Order divided into 4Ø Time Resolution Elements using a Vidicon and Moving Slit Spectrograph

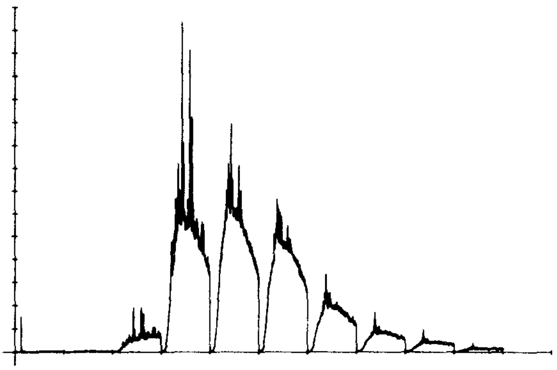


Figure 13: Xenon Flash Lamp Time Profile 1Ø Spectra @ 5Ø USEC/Spectra each Time Element 36Ø - 64Ø NM Flash Duration. 4ØØ USEC

Computer Box

Table 9 lists the design constraints that result from the above detector discussions combined with some extra system constraints. Most of the items have already been mentioned. The choice of 100 curves for storage and field update of software went hand in hadn toward the storage media selection. Both features were based upon market requests. The cost factor for the systems described were of medium importance because the design task had the pleasant requirement of performance first and cost second.

Table 9: Computer system design Constraints

1. 14 bits @ 10 μs/point
2. Data set up to 10k points
3. Large range of numbers
4. Different detectors - different controls
5. Storage of 100 curves
6. Curve processing in reasonable time
7. User designed experiments
8. Bad electrical environoments
9. Field update of software
10. Cost of medium importance

Table 10: Resultant hardware

1. 16 bit board level CPU
2. Direct memory access (DMA)
3. Floating point data manipulation
4. Floppy disk/RAM memories
5. Serial data link
6. Modular system

The hardware characteristics that resulted are listed in Table 10. The 16 bit board level CPU was forced by the data size of 14 bits and the requirement that curve processing operations on 1024 points curves occur in reasonable times. A board level CPU was selected because 16 bit chip level CPU's were not yet available with floating point capabilities. Floating point capabilities became necessary as soon as the user was given the ability to mainpulate his data. Floating point is the best way to handle the large range of possible numbers. The Special Direct Memory Access (DMA) channel was forced by the requirement to do double precision addition, for averaging, on data that enters the computer at the rate of 16 bits every 16 μsec.

The floppy disk/RAM system approach frees the system of expensive hard memory costs, allows the user to store the results of many experiments for future analysis, and allows update of the user's software by sending an inexpensive diskette instead of an expensive PROM board.

The software approach used to control the system deserves some discussion. The basic features are listed in Table 11. Curve processor base with special detector controlling software loaded on top of the curve processor is the selected approach. In this approach, the vidicon and SPD software are not two totally separate programs. This approach also forces us to keep both sets of software up to date when the curve processor is imporved. The use of overlays stored on disk and loaded when needed is the only method possible to combine a large program with the requirement for large active data memory in the computer. We used the high level language for the reasons listed in Table 12.

Table 11: Resultant Software

1. Curve processor
2. Detector drivers added to base
3. Overlay method
4. Full parameter storage on disk
5. FORTH language used

Table 12: Reasons for FORTH

1. Upper level language
2. Space efficient
3. Rapid execution speed
4. Rapid program development

Above all the other considerations presented, the key to the performance of computer box is the design of the DMA. It is this high speed input channel that allows the computer hardware to handle the high data rates while still doing averaging and mid-frame triggering. Table 13 has a number of features that are essential to the performance of the system.

Table 13: DMA Channel features

1. Direct Replacement
2. Single Precision Addition
3. Double Precision Addition
4. 1 to 64K Points
5. Variable Start Point
6. Mid Frame Start

Items one through five are fairly obvious but the 4th feature needs to be explained. Many times the detector can not be syncronized to the experiment. This means that the experiment will begin or totally occur during the middle of an X axis scan. Data before the experiment is not needed as it has no information only noise. Therefore, the DMA channel must be able to track the detector as it scans (not storing any data) and then start at any time to store data into the proper place in CPU memory. The trigger of the storage must come from the controller. Thus, this important DMA feature is truly a system feature.

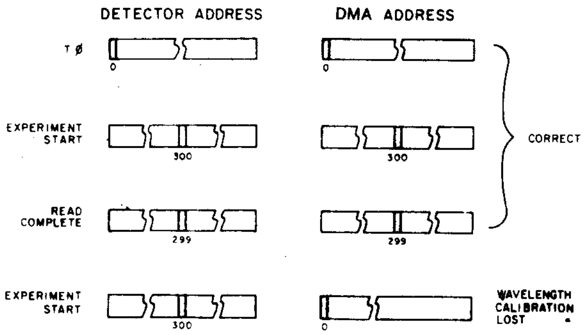


Figure 14: Examples of DMA Channel Tracking Detector Address

In the example, in Fig. 14 it is important to note that the DMA channel must stop storing data at pixel 299. If it did not, the pixels 300 and up would have the results of more pixel reads than 299 down. This exact stop point requires that a point per/frame counter exists and that this counter must be settable to various size frames.

There are many other subtle points that could be considered but they are generally of less overall importance than the preceeding points. One such thing in this category is rear panel control of the computer package via RS 232. One system feature that really fits in no ideal category and still merits discussion is source compensation. In many emission experiments the intensity of emission is directly proportional to the intensity of excitation and the excitation energy can vary. Transmission experiments are also affected by source fluctuation.

Transmission of a filter is an example of an experiment based upon a non variant source. The value of I/I_O can only be as good as the source stability. The systems we have designed all have the feature of an "extra point". This point is the digitized value of a signal presented to a rear panel BNC Connector. It is carried along by the DMA channel and is usually hidden from the user but it is available to the software to properly utilize the information. The software is designed to use this blind point as a normalization factor to eliminate source fluctuation. Of course, it is necessary for the user to present an analog signal to the rear panel BNC that is proportional to the source. (at this point the hardware design philosophy has been described in overview and the stage is set for a discussion of data manipulation. A discussion of software desgin philosophy follows in the next paper.)

Microprocessors in spectroscopic applications of imaging devices: data manipulation

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Abstract

The Optical Multichannel Analyzer (OMA 2®)* utilizes a microprocessor for detector control and for data acquisition; the same microprocessor is also used for data manipulation.

This paper reviews the processing necessary to transform numbers gathered with a typical system into useful data which describe the optical source. Emphasis is on the data manipulation rather then experimental techniques.

*OMA 2 is a registered trademark of EG&G Princeton Applied Research Corporation. (EG&G PARC)

Introduction

In the previous paper, the characteristics of imaging devices and the design criteria for minicomputer control of these devices were discussed.[1] It was shown that the minicomputer eases the problem of detector control and how it makes possible the collection of the large amounts of data available from these devices.

This paper expands the discussion into the are of processing the data obtained from the minicomputer system shown in Figure 1. The output of an optical source is monitored by a polychromator and multielement detector. The polychromator sorts the photons by their wavelengths and images them upon the detector which converts the photons into an analog signal. This analog electronic signal goes to a detector controller which digitizes the signal and transmits the digital signal to the random access memory (RAM) inside the system controller. The signal resides in RAM as a series of numbers.

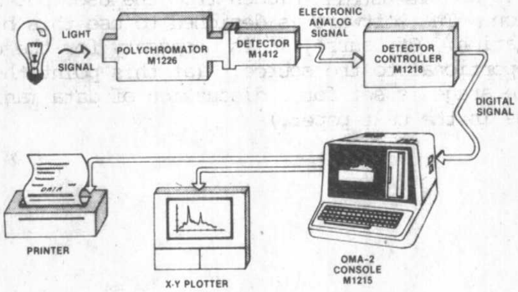

Figure 1

The intent of this paper is to illustrate through two examples how one system uses the minicomputer to process the numbers received from an imaging detector into parameters which describe the experiment in physical terms (percent transmission, irradiance, color temperature, etc.) and presents the results in a readily recognizable form.

One difference between this task and the task of detector control and data acquisition described earlier is that the data reduction can be done manually in most cases. However, for multielement arrays the number of data points would make this a very time consuming task; since the minicomputer exists for data acquisition, it should be utilized for data reduction.

The two specific examples used to illustrate the minicomputer processing are: 1) the measurement of spectral transmission of a glass filter and 2) the colorimetric measurements of an xenon flash lamp.

Instrumentation

The data described herein were acquired and processed using an EG&G PARC OMA 2. The system consists of the following items: 1) a Model 1226, 0.3m focal length polychromator of modified Czerny-Turner design; 2) a Model 1412 Solid state Detector containing a Reticon Corporation 1024s element photodiode array; 3) a Model 1218 Detector Controller which digitizes the signal using a 14 bit A/D converter; and 4) a Model 1215 System Processor which incorporates the Digital Equipment Corporation Model LSI-11 microprocessor.

The spectra were output to a Hewlett Packard Model 9872A Digital Plotter and hard copy was made on a Centronics Model 306 printer. The source for wavelength calibration was the low pressure mercury spectrum of an ordinary fluorescent lamp. The standard lamp used to calibrate the system intensity response was a 45 watt coiled-coil tungsten lamp which had been calibrated by Optronic Laboratories.

Experimental

The emphasis in this paper is placed on the data processing necessary to transform numbers taken from a multielement array, such as the silicon photodiode array, into useful parameters. Experimental problems such as stray light in the polychromators, and optical alignment, will largely be ignored.

Two examples are presented to illustrate the use of the minicomputer for the data processing. The first is a relatively simple measurement of the spectral transmission of an optical filter. The second is a more sophisticated colorimetry measurement which determines the correlated color temperature of an xenon flash lamp.

Data intepretation Part 1: background

The data initially exists in memory as a series of digital values associated with the respective detector pixels. Each number can be divided into two parts: 1) the portion of the number due to the source and 2) a portion which is independent of the source and due to the detection system. For this paper, these are called the signal and the background; the background contribution consists of detector dark current and fixed pattern clocknoise, ampliier and A/D offsets, and extraneous light entering the polychromator[2].

The first and most important task in data interpretation is the elimination of the background component from the data. The Model 1218/1412 detector system uses a peltier device to both cool and temperature regulate the silicon photodiode array. The regulation results in a detector temperature stability of 20m°C/°C ambient change at 20°C with the detector at -20°C. This regulation is necessary because of the high temperature dependence of the dark current in a silicon detector; the cooler both reduces and stabilizes the dark current[3].

Therefore, assuming electronic offsets are constant and background illumination is constant (or nonexistent), the background contribution can be eliminated by removing the source and acquiring a background spectrum which is subtracted from all subsequent spectra.

This is such a basic part of data reduction that the OMA 2 system has provision to do this subtraction automatically in both displaying the data and during data sotrage on the floppy diskette. Figure 2 shows two curves; the dirst, Curve 1, is a background spectrum, taken with the room lights off. The second, Curve 2, was taken under identical conditions except with the room lights.

Figure 3 is the result of subtracting Curve 1, Figure 2, from Curve 2. The abscissa of Figures 2 and 3 are pixel numbers and the ordinates are in counts.

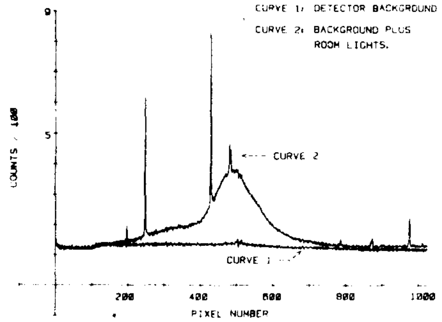

Figure 2

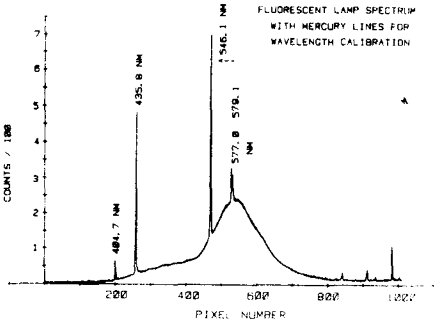

Figure 3

The interpretation Part 2: wavelength calibration

The data now reside in memory sorted by pixel number. The next task imposed upon the system is to classify the pixel numbers by some useful parameter; when using a polychromator the logical classification parameter is wavelength.

Wavelength calibration is done by viewing a spectrum with known wavelength features and fitting the features to a function $\lambda = F(X_j)$ where λ is a known wavelength line which occurs at the j^{th} pixel. For a 1024 element linear photodiode array on 0.025mm centers, mounted on a grating spectrometer whose focal length is greater than 250mm, the fit can be made to two known points using the linear function $\lambda = \lambda_o + mX$ where λ_o is the wavelength at pixel o and m is the spectrometer dispersion.

For detectors using electrostatically focused intensifiers, a satisfactory fit requires a third order polynomial since the magnification of such devices generally varies as a second order function of distance from the center of the imaging surface. Wavelength calibration in the OMA 2 is done to the third order polynomial.

$$\lambda = \sum_{k=o}^{3} a_k x^k , \qquad (1)$$