Camera and Input Scanner Systems

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Camera and Input Scanner Systems

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James R. Milch
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CAMERA AND INPUT SCANNER SYSTEMS

Volume 1448

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Session 4—Optics and Signal Processing for Image Capture
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Conference 1448, *Camera and Input Scanner Systems*, was part of a three-conference program on Image Acquisition, held at the SPIE/IS&T Symposium on Electronic Imaging Science and Technology, 24 February–1 March 1991, in San Jose, California. The other conferences were:

Conference 1447, *Charge-Coupled Devices and Solid State Optical Sensors II*
Conference 1449, *Electron Image Tubes and Image Intensifiers II.*

INTRODUCTION

Electronic cameras and input scanners have been used for many years in scientific systems and graphic arts. Today they are found in a much wider set of applications. There have been two primary drivers for this expansion. The first is the dramatic increase in the amount of computational power available to the broader market. The second is the improvement in performance of charge-coupled device (CCD) imagers. The first of these changes has driven the need for better input systems; the second has provided the means of satisfying that need. One of the important points made by the papers presented in this conference is that it takes more than a CCD imager to build a good electronic camera or input scanner. The system designer must pay careful attention to the true needs of the application. The engineer must match the optical, electronic, and mechanical components that surround the imager to those needs.

The first session of the conference dealt primarily with portable electronic cameras. These cameras compete with conventional film-based cameras in their applications. The papers described a variety of cameras and subsystems that go into such cameras. The second session was focused more on scientific applications of CCD imagers. As fast computers, image-processing software, and image-capable hard-copy printers become more readily available, the advantages of direct electronic capture in the laboratory are becoming clearer.

The third session included some examples of the design of components to fit into specific systems and the procedures necessary to ensure that these systems will meet the customer's need. The final session covered some optical systems, again designed to meet specific needs. All of these papers make clear the need to design specific systems for specific applications and to match the cost and performance of these systems to the user.

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CAMERA AND INPUT SCANNER SYSTEMS

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SESSION 1

Electronic Still/Video Cameras

Chairs

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A 1.3 megapixel resolution portable CCD electronic still camera

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ABSTRACT

Portable electronic still cameras have been available for some years although, in general, the image quality has fallen short of the 35 mm film quality benchmark. To obtain improved image capture and reproduction, higher resolution CCD imagers with wider dynamic ranges must be employed in these cameras.

A camera system composed of a 35 mm Nikon F3 camera body, a camera back containing a CCD-imager, and a portable hard drive for storing digitized images was constructed and employed to acquire images distributed over photospace. This paper describes the camera's hardware and capabilities, the software post-processing, the camera's characteristics, and a method for evaluating the camera's performance.

1. INTRODUCTION

Portable electronic still cameras possess numerous advantages as well as disadvantages compared to film-based cameras. Among the advantages are rapid image availability without the chemical processing step required by film, and direct input capability to computers for applications requiring image data. However, while the image quality obtainable with these cameras may be acceptable for display on a video monitor, their overall quality has proven to be too low for many applications. A higher performance camera system is required to satisfy the future needs of markets involving surveillance and security, visual record databases, military and industrial operations, law enforcement agencies, desktop publishing, and professional and sports photographers. Towards this end, a megapixel resolution digital CCD electronic still camera was constructed. The principal goal of this effort was to devise an experimental camera that produced high quality images and, further, one that was both portable and easy to use.

In the construction of an electronic still camera, one may invest significant design effort in the mechanical camera components, or, alternatively, one may retrofit an existing film camera with an electronic imaging accessory. The latter approach has the obvious advantage in that excellent mechanical performance may be obtained with minimal developmental effort, and this is the approach that was employed. A description of the complete experimental camera system developed for, and with, the Professional Photography Division of Eastman Kodak Company is given herein. This paper presents an overview of the camera system composed of the camera body and accessory electronic back, the interface base unit, and the digital storage unit. A method for evaluation of the camera's performance is also described.

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2. ELECTRONIC STILL CAMERA SYSTEM

2.1 Camera Back and CCD imager

The selection criteria for the camera body were that it had to possess a high-quality shutter mechanism for controlling exposure and have proven reliability. The Nikon F3 camera body is recognized by professionals to have these qualities. It was selected for this reason, as well as for the fact that a multitude of high-quality Nikon lenses are commercially available for the camera. As an extra bonus, users of the camera found its traditional shape, feel, and operation an invaluable aid in quickly achieving proficiency in capturing still images.

The conventional film back was removed from the camera body and replaced with a somewhat larger housing enclosing the CCD imager and support electronics. A base unit was also attached to the camera in the position normally occupied by a film-advance mechanism. The experimental camera body, back, and interface base unit are shown in Fig. 1 along with the digital storage unit and the tether cable which connects the storage unit to the camera.

The KODAK KAF1300LC Image Sensor in the camera back, manufactured by Eastman Kodak Company, is a full-frame photocapacitive device possessing 1280 (horizontally) by 1024 (vertically) active photosites for a total of ≈1.3 million photosites. The square photosites measure 16 µm on a side, yielding an active imaging area of 20.48 mm by 16.38 mm, which is somewhat smaller than the 35 mm format of the film it replaces. The large photosite area with a 70% fill factor was designed to provide an exceptionally high exposure index suitable for electronic still applications. The KODAK KAF1300LC also exhibits a wide (peak signal-to-dark noise) dynamic range of 75dB.

Antiblooming was required in this application to control the specular highlights often encountered in real world scenes. A lateral overflow drain in the KODAK KAF1300LC provides effective antiblooming control up to 1000% of full well levels. Scene information was unaffected in locations adjacent to saturated photosites.

An integral color filter array (CFA) on the sensor served to separate the red, green, and blue scene information. The "three-green" CFA pattern[1,2] is shown in Fig. 2. This pattern allocates 75% of the photosites to detecting green scene detail, and the remaining 25% to detecting red and blue scene information. The CFA pattern was designed to sample images in a manner compatible with the human visual system in that the high sampling rate for green (luminance) scene information produces a high degree of scene detail and sharpness in captured images, while the sparse sampling for red and blue provides lower resolution chroma information.

The CCD imager is positioned within the camera body at the plane normally occupied by the film. In this way, the viewfinder accurately reflects the focus of images on the imager. The imager was aligned within the back using the surface of the film guide rails as a focal plane reference.

Two circuit boards within the camera back performed the tasks of controlling the imager and conditioning the CCD analog output signal. A programmable controller chip generated clock signals, while additional circuitry performed analog signal processing including correlated double sampling, amplification and dark level subtraction, and analog-to-digital conversion (ADC), as shown in Fig. 3.

The interface base unit, mounted under the camera body, served as the pathway for data and control signals between the camera back, camera body, and the digital storage unit.

2.2 Digital storage unit

The digital storage unit performed the combined functions of user interface, overall system control, image storage and display, computer interface, and power regulation and supply. For the user interface, the front panel pushbutton switches seen in Fig. 1 allowed the user to select options such as automatic or manual saving of each acquired image and adjustment of the electronic gain in the analog signal processing circuitry in the camera back to change its effective ISO rating. A small alphanumeric LCD readout was present on the front panel for display of camera system status information.

A 100 MByte hard disk drive served as the storage medium for image data. Since data compression was not employed to reduce the amount of image data, two seconds were required to save each uncompressed image to disk. A frame buffer was used to temporarily hold the data from a single image as it streamed at a high rate from the camera back into the storage unit. This frame buffer also served as video RAM for logic that produced an NTSC composite monochrome video signal, available on a BNC connector located on the side of the digital storage unit. The most recently captured image could thus be automatically displayed on an external monitor via this connector for the purpose of image verification.

Power for the entire camera system was provided by a 12V battery of sufficient capacity for capturing and storing 76 images, equal to the full capacity of the hard disk.

2.3 Overall Camera Operation

To capture an image, the user turned on the digital storage unit, selected the desired control options, cocked the F3 shutter mechanism with the film advance lever, and focused and shot the image. The system responded to a "soft-touch" on the F3 shutter release button by enabling the camera's electronic circuitry and preparing to capture an image. Completely depressing the shutter release button initiated the capture operation. Acquired images were sequentially numbered by the control microprocessor. The user interface allowed individual images to be retrieved from the hard disk for examination, or, if desired, deleted from the disk by referencing the image number. After each image was shot, the image data would be automatically saved to disk unless the user selected the manual save option. A small 2" diagonal LCD video monitor was used to view each captured image to verify the exposure. A zoom function allowed the user to enlarge the image by a factor of four and examine fine image detail. In this way, the user could ascertain whether objects of interest had been captured with proper focus and at the optimal exposure level.

The equivalent ISO at the minimal gain setting was found empirically to be 320 for the green photosites and somewhat lower for the red and blue. The gain select option allowed the user to compensate for low light level scenes by amplifying the CCD signal. Although additional gain resulted in increased noise in the image data, it enabled faster shutter speeds to be used for low light level scenes of moving objects photographed where motion blur would be unacceptable.

Following a session of image captures, data saved in the digital storage unit was downloaded to a microcomputer for permanent storage and for image processing. A standard SCSI interface served as the link to the computer.

2.4 Image processing

The data for one camera image consisted of approximately 980 Kilobytes of green and 327 Kilobytes of red and blue scene information. Processing of this data was required to correct for bad pixels, to white balance the data, to estimate scene information that was missing due to the incomplete sampling of the scene chroma information, and to color correct the data. To correct bad pixels, the value of the nearest neighboring pixel was substituted for the defective one when no deleterious effects were observed in the final image. For scenes where this method was unacceptable, two dimensional interpolation routines were employed. Following the interpolation and white balance operations, complete 1.3 Megapixel red, green, and blue image planes were obtained by an interpolation method which first estimated the green pixel information required in the chroma columns, and then estimated the missing red and blue pixel information using the image contours and detail contained in the green image plane.[1]

3. PHOTOSPACE PERFORMANCE TEST

A camera's performance may be judged using either analytical and subjective (perceptual) metrics. A characterization employing both approaches is described in this section.

3.1 Characterization

To verify proper imager positioning within the camera back, the camera was focused by eye through the viewfinder at a distance of 1 meter on a radial resolution target. The 55 mm micro-NIKKOR lens on the camera was set at f = 2.8 for minimum depth of field, and the CCD imager position was adjusted to obtain maximal sharpness at all points in obtained images. Following this calibration, it was verified that any change in focus resulted in a reduction in sharpness of images obtained from the test target.

Ideally, although CCDs have a linear response to light, the anti-blooming mechanism in a CCD may compromise the desired linear response. The experimental ESC output linearity was measured by capturing a linear-step neutral-gray test target that extended over the full dynamic range of the camera. Fig. 4 shows one line of data from the camera image for the test-chart. It can be seen that the lateral overflow drain (LOD) used for anti-blooming in the KODAK KAF1300LC imager did not significantly impact the system linearity.

In general, ESCs do not have the 10 stops of dynamic range that film products do, and it was found to be extremely important to meter scenes carefully so as to use the full dynamic range of the camera. Underexposing scenes resulted in images with unacceptable noise levels, while overexposed scenes yielded images with large, visually unappealing detail-less regions. The linear-step test-target is one means of assessing the camera's capability for capturing scene dynamic range.

A characterization of the ESCs variation of signal-to-noise (S/N) with exposure and with integration time is also important. This can be performed by uniformly illuminating a flat neutral target and acquiring an exposure series. Ideally, all pixels values in such an image will be identical, but the pixel values will exhibit a normal distribution due to system and imager noise. The noise component is composed of terms which increase with exposure such as photon shot noise, and terms that are independent of exposure, such as clock feed-through noise. This S/N level can be used to determine the optimum F/# and integration time combination for best performance at a given light level with shorter integration times yielding lower noise images. A limit on the allowed noise may also be used to define when a flash light source should be employed to reduce the exposure time.

The limiting resolution of the experimental ESC was evaluated by capturing images of resolution targets. It was verified by measuring the lens MTF independently and cascading that result with the analytical response function from the imager and it's optical prefilter. To complete the camera calibration, the camera's focal plane shutter speed and lens aperture accuracy were measured and recorded.

3.2 Photoshoot Test Plan

The plan for the camera evaluation was to shoot scenes evenly distributed over the range of camera to subject distances and normal light levels comprising a two-dimensional photospace. The actual distribution of the scenes captured is shown in Fig. 5. The scenes consisted mainly of 'real world' images including shots of buildings and people, and often involved some additional interesting attribute such as high contrast, included sun, extreme close-up, and mixed light sources.

The scope of comparison was broad. The ESC images were evaluated based on how well they reproduced the original scene, as well as by comparison with the scene reproduction of a number of film systems. Table 1 lists the photographic systems and their components used for the ESC and the film cameras.

Capture Media	Camera	Lens
KODAK EKTAPRESS GOLD 400 Film	Nikon F3	uNikkor 85 mm
KODAK EKTAR 25 Film	Nikon F3	uNikkor 85 mm
KODAK GOLD 200 Film	Nikon F3	uNikkor 85 mm
KODAK KAF1300LC Image Sensor	Nikon F3	uNikkor 55 mm

Table 1: Photographic Systems Used in Evaluation

The films were selected for various attributes: KODAK EKTAR 25 film, for it's fine grain and sharpness; KODAK EKTAPRESS GOLD 400, a popular professional film, selected for it's medium contrast rendition, and KODAK GOLD 200, a popular consumer film, selected for it's high contrast and 'snappy' color rendition. Each of the films was procured in quantity from a single batch and kept under refrigeration to insure uniform characteristics from roll to roll throughout the testing. For similar reasons, film developing was done in a single batch with controls in place to insure uniformity.

Each film-camera/lens pair used in the experiment was characterized with regard to shutter speeds and lens apertures. Lenses were matched to camera bodies in such a way as to compensate for errors in their performance.

Since the imager captures image data over a smaller area than the 35 mm format, the ESC image has a reduced field-of-view compared to a conventional 35 mm picture. To match the vertical field-of-view of all cameras, a 0.65 x shorter focal length lens was used on the ESC. Micro-NIKKOR lenses of 55 mm and 85 mm focal lengths were employed for the ESC and film cameras respectively, as indicated in Table 1.

3.3 Conducting the Test

Conducting the photoshoot involved ensuring that near-identical scenes were recorded by all cameras. Ambient light levels were monitored, spot-metering was performed to ascertain the overall scene contrast, and the camera-to-subject distance was controlled to ensure continuity of composition between cameras. A fixed-position tripod with a quick-release camera mounting system served to ensure field-of-view uniformity between the cameras. The proper exposure for each film speed was determined by incident light metering, and the apertures used for each camera were correlated to match the depth-of-field that resulted from the difference in lens focal lengths. A half-stop exposure sequence was shot with each camera for each scene.

Following the captures and processing, each scene will be printed to 3.5 by 5 inch size, and an assessment of perceptual evaluation of image quality will be conducted. The results of this evaluation will be compiled and used to derive an overall performance metric for each system. This includes an impact weight of each photospace test point, indicated by frequency studies of customer pictures. Two of the images from the perceptual evaluation are shown in black and white in Figs. 6 and 7, the first to be used for assessing dynamic range, the second for assessment of fine detail reproduction.

Regarding the experiment, it was found to be difficult to maintain perfect control over lighting levels under real-world conditions. For example, if the lighting level changes by 1/2 stop during the shooting, the shadows and highlights in the scene will be sufficiently different so as to cause perceptible distinctions between the prints from the different cameras. Therefore, given the desirability of precisely attaining a particular exposure, scenes were shot by waiting for moments when the light level attained a desired value. A caution concerning this approach is that when the light does not return quickly to the desired level between shots, the changing position of the sun will cause movement in the positions of shadows and highlights.

3.4 Design Improvements

The performance evaluation indicated some general items of importance in ESC design. Chiefly, the camera electronics must be designed with low noise as an item of major emphasis. Many scenes, especially indoor shots, are illuminated weakly at the blue end of the spectrum and thus a noise level which is acceptable for the strongly illuminated green photosites may cause speckle in data from the weakly illuminated blue photosites. An imager-noise limited camera system design would be optimal.

As new technology becomes available, it would also be advantageous to put the capabilities of this experimental camera in a smaller, lighter package. This would improve the camera's portability and open up applications where these aspects are required. The chief technological improvement required would be to replace the hard disk with an alternative storage medium of equal capacity and smaller size and weight.

4. SUMMARY

An electronic still camera intended for general use must operate robustly to meet the needs of today's wide range of photographic applications. Such a camera must capture high-speed, high-resolution, color images. The design approach described in this paper achieves these requirements with an electronic imaging accessory added to a high quality camera body. The experimental camera system, constructed using an Eastman KODAK KAF1300LC megapixel resolution CCD imager and Nikon F3 professional camera body, had the following characteristics:

CCD Resolution:	1280(H) x 1024(V) photosites
Equivalent ISO:	320
Spectral Range:	400 to 700 nm
A/D Resolution:	8 bits / pixel
Image Capacity:	76 images saved on a hard disk
Image Verification:	via LCD monitor
Computer Interface:	SCSI
Image Processing:	Software on a personal computer
Power:	12V Battery
Storage Unit Weight:	approximately 12 pounds

This camera allowed for images to be captured on-site and image processed on a personal computer providing near-instant access to images in color.

5. REFERENCES

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2. John A. Weldy, "Optimized design for a single-sensor color electronic camera system," *Optical Sensors and Electronic Photography*, SPIE vol. 1071, pp. 300-308, 1989.

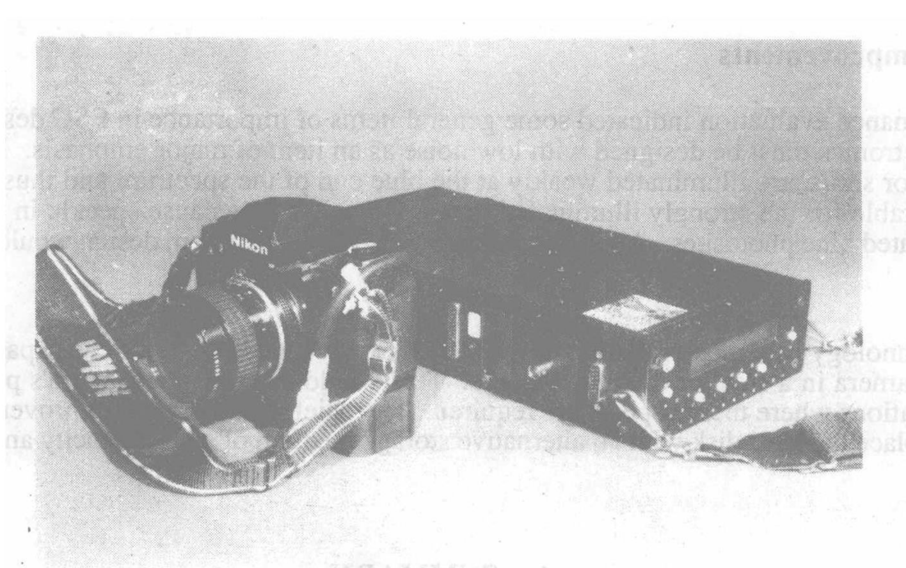

Fig. 1. Electronic Still Camera

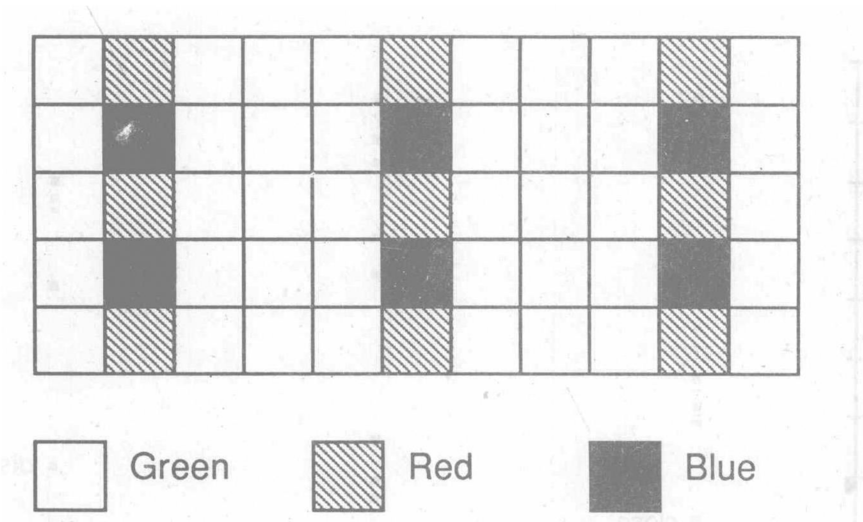

Fig. 2. Three-Green CFA Pattern

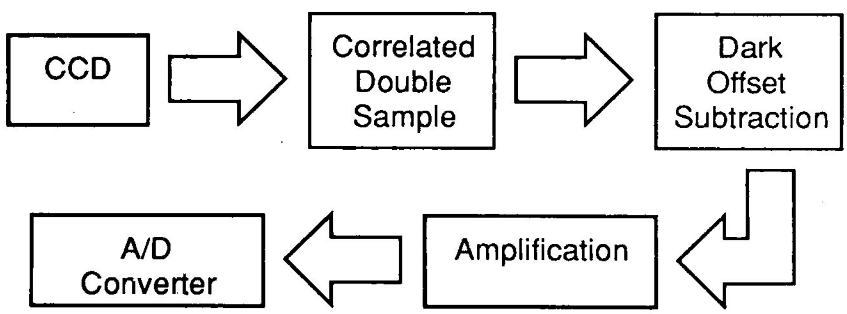

Fig. 3. Camera Back Analog Signal Processing

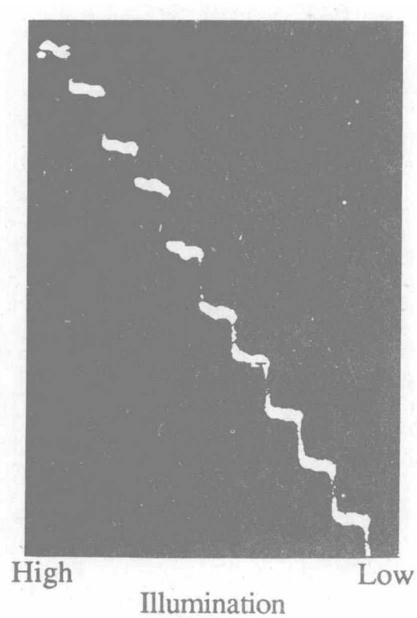

Fig. 4. ESC Linearity

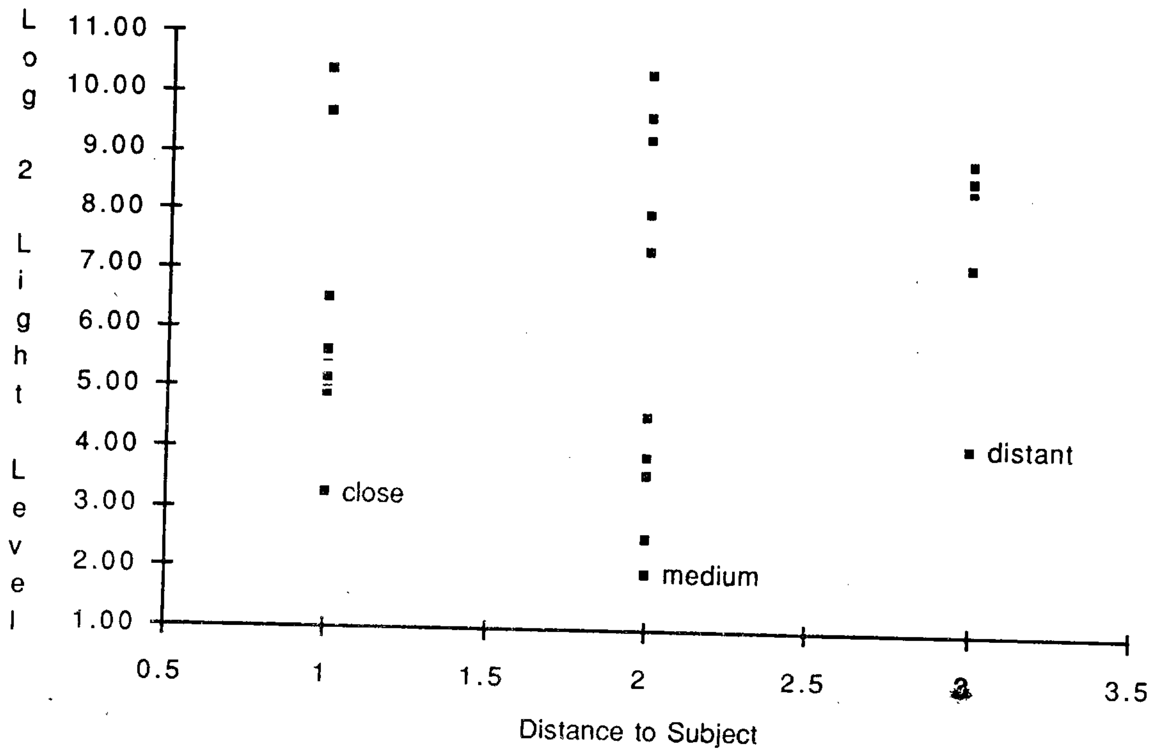

Fig. 5. Distribution of Scenes in Photospace