Estimation of electro-optical payload performance

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Evaluation of the performance of electro-optical payload within the laboratory is discussed. This method is valid for the system, which has output in the form of electrical signal though the input is optical in nature. The methodology enables the evaluation of entire configuration of electro-optical payload comprising of lens system, photo detecting device (one or two dimension array) and processing electronics. The data collected can also be utilized to compute different parameters to estimate National image interpretability rating scale of payload.

Keywords: Electro-optical, Payloads, Payload resolution, Payload performance evaluation, National image interpretability rating scale

IPC Code: H02G

1 Introduction
Electro-optical payload, commonly used for reconnaissance and surveillance, viz. thermal imager and CCD camera, consists of zoom lens and array of pixel. Various methods are discussed in the literature1-3 to evaluate the performance of optical and electro-optical systems. The techniques used for the assessment of performance of optical systems are not utilized for evaluation of CCD camera, as these electro-optical payloads output is time variant voltage/current signal. In addition, image formed in the output for these payloads cannot be utilized to generate intensity varying signal as a function of space domain variable i.e. line spread function [LSF]. In the present method, camera is made to observe the sharp ‘edge’. The electrical signal of pixels, constituting a line, is captured with the help of Digital oscilloscope and waveform is scanned to generate time variant electrical signal. Fast Fourier Transformation is performed to convert time domain data into space domain frequency response.

2 Experimental Details
The experimental set-up is shown in Fig. 1; where the payload is aligned to an edge so that its image is displayed on the video monitor. The edge is oriented in vertical direction so that pixels are scanned within a line of the CCD array. In addition approximately half of the pixels are illuminated with maximum allowable intensity and remaining pixels are obscured with physical size of edge.

The video signal from camera is connected to Tektronix TDS 3054B 500 MHz digital oscilloscope for measurement. The image formed by the payload, on the video monitor has been investigated. Measurements are carried out for following configurations viz. (i) Payload camera configuration (based on M/S PULNiX TM 765i CCD camera); (ii) Camera configuration –II (based on M/S PULNiX TM1300 CCD camera); (iii) Camera configuration–III (Payload camera + TV monitor)

Following settings are ensured before proceeding to measurement: The iris drive is adjusted so that video level shall be close to 700 mV. Focus drive is adjusted to achieve sharp image of the edge. This is done while observing the oscilloscope trace. The transition from maximum to minimum level shall be within least time duration. The edge orientation is kept in vertical direction to avoid the crossing over of the pixel line at the edge. Utilization of 75 ohm termination cable for interconnecting of video signal to minimize loading. Typical video output signal captured with the oscilloscope from payload camera is shown at Fig. 2.

The video signal instantaneous voltage [in mV] is measured with oscilloscope at every 4 as well as 20 nano sec interval from minimum to maximum level (close to the transition). Fast Fourier Transform (FFT) is performed on this time domain data to get frequency domain information. The interpretation of data and steps involved are described vide the following example:

2.1 Computation of space domain data for Payload camera
Pixel Configuration: 752 [H] *582 [V]; Line Time [CCIR]: 52 µs; Number of pixels in a line: 752; Pixel

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dimension: 11 x 11 µm; Zoom lens focal length: 160 mm; Input data interval: 4 *10^{-9} s; Angle subtended by Pixel: \( \frac{11 \text{ µm}}{160 \text{ mm}} \); or: 68.75 µrad; 4*10^{-9}s corresponds: \( 752*4*10^{-9}/52*10^{-6} \); 57.8 *10^{-3} pixel; Also 4*10^{-9}s corresponds to angle: \( 57.8*10^{-3}*68.75 \) µrad or: 3.97 µrad; Corresponding sampling frequency: \( 1/[2*57.8*10^{-3}*68.75 \text{ µrad}] \); [spatial] = \( 10^{-3}/[2*57.8*10^{-3}*68.75 \text{ mrad}] \) or: 126 cyc./mrad.

In other words, 4 nano sec time interval corresponds to 126 cyc/mrad spatial frequency. Factor 2 in the denominator in the frequency expression is introduced to convert space domain frequency as Lp/mrad. In fact Lp/mrad or cyc/mrad unit is frequently used for expressing resolution of an electro-optical system.

In a similar manner, the frequency domain information is evolved for Camera configuration–II. The basic data is mentioned below: Camera pixel configuration: 1300[H]*1030[V]; Line time: 18.3*10^{-6} s; Data interval: 4*10^{-9} s; Pixel size: 6.7*6.7 µm; Zoom lens focal length: 90 mm; Angle subtended by pixel: \([0.067/90]\) rad = 75 µrad; Spatial sampling frequency :\( 1/[2*20 \text{ µrad}] =25 \text{ cyc./mrad} \).

FFT is performed on the time domain data to generate the frequency [cyc/mrad] scale and their normalized amplitude. The FFT resolution [cyc/mrad] are mentioned at second column of Table 1 while frequency responses for all the aforesaid cases are shown in Fig. 3.

The cut-off frequency limits [#], obtained from FFT data for 10% of modulation/contrast, are summarized in third column of Table 1. In the present air to ground scenario of low to medium altitude reconnaissance or surveillance, this cut-off limit of modulation or contrast is highly realistic.

In case of TV systems the resolution is commonly defined in terms of \( R_{TV} \) [TVL], which is evaluated in Table 1.

### Table 1 — Correlation of experimental and reported data

<table>
<thead>
<tr>
<th>Camera Configuration</th>
<th>FFT freq resolution [cyc/mrad]</th>
<th>Cut-off # freq limit ( R_{lp} ) [cyc/mrad]</th>
<th>Cut-off limit for Pixel Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload Camera</td>
<td>1.0</td>
<td>7.0</td>
<td>770@ 577</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>752@ 582@</td>
</tr>
<tr>
<td>Camera Configuration-II</td>
<td>1.1</td>
<td>6.6</td>
<td>1330@ 1005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1300@ 1030@</td>
</tr>
<tr>
<td>Camera Configuration-III</td>
<td>0.45</td>
<td>3.3</td>
<td>398@ 298@</td>
</tr>
</tbody>
</table>

@ Camera specifications

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**Fig. 1 — Experimental set-up**

**Fig. 2 — Video signal from payload camera**

**Fig. 3 — Comparison of frequency domain results (for different configurations)**
from \( R_{lp} \text{[cyc/mrad]} \) with the help of following expression:

\[
R_{TV}[TVL] = R_{lp}[cyc/mrad] \times \text{FOV}_H[mrad] \times 2[TVL/cyc] \tag{1}
\]

where \( R_{TV} \text{[TVL]} \) term is referred to the pixel’s limit rather than optical resolution because oscilloscope measurements are carried out at pixel level. Horizontal FOV shall be used while calculating the data of forth column of Table 1 as the measurements are done for a line of pixel, which forms horizontal Field of View. As both the cameras utilize square pixels, the value of \( R_{TV} \) for vertical dimension of CCD, [fifth column], is just \( \frac{3}{4} \) of corresponding data of forth column. From pixel data [forth and fifth columns of the Table 1], analog TV resolution for both the cameras is calculated using Kell factor. Thus \( R_{TV}[H] \) and \( R_{TV}[V] \) for Payload camera are found to be 542*380, which are in close agreement with the manufacturer’s specification 560 *400 TVL, respectively.

3 National Image Interpretability Rating Scale

National Image Interpretability Rating Scale [NIIRS] is developed regarding aerial image quality. The general image quality equation\(^5\) [GIQE] provides predictions for NIIRS as a function of quality attributes of scale, resolution, sharpness, contrast and noise. The equation is reproduced as:

\[
\text{NIIRS} = 11.81 + 3.32 \times \log_{10} \left( \frac{\text{RER}}{\text{GSD}_{GM}} \right) - \left( 1.48 \times \text{H}_{GM} \right) - \left[ \frac{\text{G}}{\text{SNR}} \right] \tag{2}
\]

Ground sampled distance (GSD) in inches is easily obtained from mission parameters i.e. camera FOV, altitude of flight and line of sight (LOS) slant range etc. RER and overshoot height [H\(_{GM}\)] are also evaluated from the edge response data. The edge responses for cameras with and without overshoot correction, due to MTFC, are shown at Figs 4 and 5, respectively.

The data collected for the edge response is normalized and shown in Fig. 6 for DTV payload, [Payload camera], against pixel. RER is measured between two points that are 0.5 pixel from the edge location [0 marking on X-axis refers the edge]. GSD RER and \( G_{M} \) values obtained for Payload camera are 11.5, 0.45 and 1.02, respectively. These values are found to be within the proposed\(^5\) limits. The data for TM 1300 camera is not mentioned as the same is not configured as payload.

\[
\text{Fig. 4 — Edge response from payload camera [with overshoot]}
\]

\[
\text{Fig. 5 — Edge response from camera configuration-II [without overshoot]}
\]

\[
\text{Fig. 6 — RER evaluation from edge response}
\]
It is stated\(^5\) that the predominant parameters for NIIRS expression are GSD, RER and \(H_{GM}\). G and SNR have smaller effect. The NIIRS for Payload camera is worked out as Scale-4 which translates as identification of individual tracks, rail pairs, control towers, moving vehicles and single story buildings etc.

### 4 Discussion

The \(R_{TV}\) results for both the cameras are found in close agreement with reported camera specifications. However, the figures mentioned at third row show the pixel density as 398 *298 TVL. The resolution becomes 278*208 TVL utilizing Kell factor. These resolution values are not in agreement with the manufacturer’s data [540*380 TVL] in case measurement is carried out for Payload camera combination using resolution chart. This obviously indicates that the degradation of resolution for the third case is not merely due to TV monitor. Because the monitor is part of experimental set-up while measuring resolution using Chart. In addition, the pixel line density and line frequency of Camera configuration-II, used to evaluate configuration-III, are two and three times, respectively in comparison of Payload camera.

The separation between edge and camera is kept as \(\approx 1.7\) M which is beyond the minimum focusing limit of the zoom lens. In fact same distance is also required during resolution chart measurement. The degradation may be due to the use of TM 1300 CCD camera as a measuring device. The use of still higher density camera may improve the results. This ambiguity needs to be studied and resolved.

### 5 Conclusion

NIIRS estimation will be further modified soon after the factors viz. Noise Gain G and signal to noise ratio SNR are being interpreted. Though the effect is going to be marginal, the system performance degradation due to mounting platform base motions could be taken into account to predict the payload response, for a known platform, in flight. In case of thermal payloads, similar experimentation could be adopted. The only difference is that the edge shall have known temperature contrast with respect to surroundings.

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### References