Advantages of customized optical design for aerial survey cameras

PHOWO 2009 - Handout

08.09.09

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Topics:

1) Historical Background
2) Customized Optical Design matching the Sensor Properties
3) Environmental Effects on Image Quality
4) As-Build-Performance simulated and measured
5) Conclusion
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Historical Background – Aerial Survey Cameras made by Carl Zeiss

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Model</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910</td>
<td>Metric Balloon Camera</td>
<td>MRB</td>
<td>Carl Zeiss Jena</td>
</tr>
<tr>
<td>1916</td>
<td>Hand held Airplane Camera</td>
<td>LMK</td>
<td>Carl Zeiss Jena</td>
</tr>
<tr>
<td>1922</td>
<td>Analogue Aerial survey Camera</td>
<td></td>
<td></td>
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<tr>
<td>1950s</td>
<td>Analogue Aerial survey Camera</td>
<td></td>
<td></td>
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<tr>
<td>1980s</td>
<td>Analogue Aerial survey Camera</td>
<td></td>
<td></td>
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<tr>
<td>2003</td>
<td>Digital Mapping Camera</td>
<td></td>
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<tr>
<td>2009</td>
<td>Digital Aerial Survey Camera</td>
<td></td>
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<tr>
<td></td>
<td>DMC optics</td>
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<td></td>
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<tr>
<td></td>
<td>RMK-D optics</td>
<td></td>
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</tbody>
</table>

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Criteria: Modulation Transfer Function (MTF)

Modulation as measure for the ability to detect features

\[ V(v) = \frac{I_{\text{max}}(v) - I_{\text{min}}(v)}{I_{\text{max}}(v) + I_{\text{min}}(v)} \]

\[ v_{\text{max},o} = \frac{1}{(F/\# \lambda)} \text{ [LP/mm]} \] (diffraction limited = ideal)

\[ F/\# = 4 \quad \lambda = 0.55/1000 \text{mm} \]

\[ v_{\text{max},o} = 450 \text{LP/mm} \]
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Customized Optical Design matching the Sensor Properties

DMC Pan Lens
designed for
12\mu m Sensor

RMK-D Lens
designed for
7.2\mu m Sensor

Photographic
SLR Lens comparable
to RMK-D Lens

Compare designs with respect to resolution limit of digital sensor (Nyquist frequency).

\[ v_{\text{max},s} = \frac{1}{2 \text{ Pixel size}} \text{ [LP/mm]} \]

\begin{align*}
\text{Pixel size} &= 12/1000 \text{ mm} \\
v_{\text{max},s} &= 42\text{LP/mm}
\end{align*}

\begin{align*}
\text{Pixel size} &= 7.2/1000 \text{ mm} \\
v_{\text{max},s} &= 70\text{LP/mm}
\end{align*}

Design criteria > 40\% \at \frac{v_{\text{max},s}}{2} \Rightarrow \text{Visibility}

Design criteria < 40\% \at v_{\text{max},s} \times 2 \Rightarrow \text{Suppress Aliasing}
Modulation Transfer Function (MTF) evaluated for 12um Sensor Pixel

Design criteria fulfilled for DMC Pan lens.

Typical photographic lens correction. Emphasis on center of field. It is allowed for less correction effort at edge of field.
Customized Optical Design matching the Sensor Properties

Modulation Transfer Function (MTF) evaluated for 12um Sensor Pixel

Design criteria fulfilled for DMC Pan lens.

Visibility criteria only fulfilled within 80% of image field.
Aliasing criteria not fulfilled within center of image field.

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Customized Optical Design matching the Sensor Properties

Modulation Transfer Function (MTF) evaluated for 7.2um Sensor Pixel

Design criteria fulfilled for RMK-D lens.

Nyquist / 2 35LP/mm
Nyquist 70LP/mm
Nyquist x 2 140LP/mm

Design criteria only fulfilled within 70% of already reduced RMK-D image field.

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Comparison customized design vs. standard photographic lens

+ Performance criteria fulfilled across entire field of view
+ Uniform Performance across the field of view
+ Performance matched to sensor with respect to sensor size, resolution and aliasing

- Photographic lens may fulfill performance requirements of aerial survey camera systems only for reduced field of view or at lower speeds.
- This is not an issue for photography, where the center of field of view is of most importance.
- It may however limit the performance for photogrammetric applications.
Topics:

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Modulation Transfer Function (MTF) evaluated for 5000m height change

DMC Pan Lens

Design criteria fulfilled for DMC Pan lens over a very large pressure range. Visibility remains unchanged.

Photographic SLR lens

Design criteria only fulfilled within 80% of image field. Visibility changes dramatically with change in pressure.
Modulation Transfer Function (MTF) evaluated for 5000m height change

**RMK-D Lens**

Design Criteria fulfilled for RMK-D lens over a very large pressure range. Visibility remains unchanged.

**Photographic SLR lens**

Visibility criteria not fulfilled within entire image field! Visibility changes significantly with change in pressure!
Modulation Transfer Function (MTF) evaluated for 40°C Temperature change

Design criteria fulfilled for RMK-D lens over a very large temperature range. Visibility remains unchanged.
Modulation Transfer Function (MTF) evaluated for 40°C Temperature change

Design criteria is not fulfilled within entire image field.
Ability to detect features changes significantly with change in temperature.
Comparison customized design vs. standard photographic lens

+ Full performance with respect to pressure variations
+ Full performance with respect to temperature variations
+ Constant performance with respect to environmental effects

- Photographic lens may significantly defocus and change image size due to environmental changes.

- This is not an issue for photography, where by refocusing the environmental changes are compensated and magnification stability is not required.

- It may however cause severe problems for photogrammetric applications.
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Modulation Transfer Function (MTF) evaluated for 100 DMC PAN Lenses at Nyquist/2.

Simulation Predictions of 100 PAN Lenses  Production Results of 100 PAN Lenses

Design criteria fulfilled for DMC-PAN lens in theory over a large number of lenses.

Design criteria fulfilled for DMC-PAN lens in practice over a large number of lenses.

Full performance over a large number of lenses both in theory and practice. Agreement between theory and practice => defined production process !
Customized design

+ Full performance with respect to large number of produced lenses

+ As-build performance very predictable due to defined engineering processes
  => low development risk

+ As-build performance constant over a large number of lenses due to defined production processes
  => low production risk and ramp-up risk
Advantages of customized optical design for aerial survey cameras

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Advantages of customized optical design

+ Performance criteria fulfilled across entire field of view
+ Uniform Performance across the field of view
+ Performance matched to sensor with respect to sensor size, resolution and aliasing

+ Full Performance with respect to large pressure variations
+ Full Performance with respect to large temperature variations
+ Constant Performance with respect to environmental effects

+ Performance criteria fulfilled with respect to large number of produced lenses
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  => low development risk
+ As-build performance constant over a large number of lenses due to defined production processes
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Conclusion

There are many advantages using a customized optical design.

It takes a customized mechanical design that supports the superior performance and stability of the optical lens design to achieve superior as-built lens performance. And it takes the ability to build and adjust according to the requirements of the optical and mechanical design.
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Advantages of customized optical design for aerial survey cameras

We make it visible.