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Panoramic Mosaicing with a $180^\circ$ Field of View Lens

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Outline

Talk overview:

- > 180° FOV lens — FC-E8 description
- Spherical retina
- Mapping of light rays
- Complete camera model
- Procedure for computing the parameters of the model
- Experimental results
- Example of an application
**FC-E8 description**

![Image of FC-E8 lens](image1)

**Specifications (source - Nikon)**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lenses</td>
<td>Five elements in four groups</td>
</tr>
<tr>
<td>Field of view</td>
<td>183°</td>
</tr>
<tr>
<td>Dimensions</td>
<td>ø74 mm x 50 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>205 g</td>
</tr>
</tbody>
</table>
Traditional planar retina cannot be used for FOV $> 180^\circ$

Spherical retina must be used for omnidirectional images
Mapping of the light rays

Projection models [Fleck, 1995]:

- perspective projection... \( r = k \tan \theta \)
- stereographic projection... \( r = k \tan \frac{\theta}{2} \)
- equidistant projection... \( r = k\theta \)
- equisolid angle projection... \( r = k \sin \frac{\theta}{2} \)
- sine law projection... \( r = k \sin \theta \)

Model of the Nikon FC-E8:

\[
r = a \tan \frac{\theta}{b} + c \sin \frac{\theta}{d}
\]
Experimental setup, known angle $\theta$ correspond to concentric circles in the image.

Model fitting error [pixels]

$$r = a \tan \frac{\theta}{b} + c \sin \frac{\theta}{d}$$

Model fit for stereographic projection and our function.
**Complete model calibration**

Extrinsic parameters

\[ \tilde{X} = RX + T \]

Mapping of the light rays

\[ r = a \tan \frac{\theta}{b} + c \sin \frac{\theta}{d} \]

\[ u' = r \cos \varphi \]

\[ v' = r \sin \varphi \]

Intrinsic parameters (zero skew)

\[
\begin{pmatrix}
  u \\
  v \\
  1
\end{pmatrix} =
\begin{pmatrix}
  1 & u_0 \\
  \beta & \beta v_0 \\
  1 & 1
\end{pmatrix}
\begin{pmatrix}
  u' \\
  v' \\
  1
\end{pmatrix}
\]

\[
\begin{pmatrix}
  u \\
  v \\
  1
\end{pmatrix} =
\begin{pmatrix}
  1 & u_0 \\
  \beta & \beta v_0 \\
  1 & 1
\end{pmatrix}
\begin{pmatrix}
  \quad \quad \quad \quad r(\tilde{X}, a, b, c, d) \cos \varphi(\tilde{X}) \\
  \quad \quad \quad \quad r(\tilde{X}, a, b, c, d) \sin \varphi(\tilde{X}) \\
  1
\end{pmatrix}
\]

\[ \tilde{X} = RX + T \]
Objective function

\[
\mathbf{u} = \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & u_0 \\ \beta & \beta v_0 \\ 1 \end{pmatrix} \begin{pmatrix} r(\tilde{X}, a, b, c, d) \cos \varphi(\tilde{X}) \\ r(\tilde{X}, a, b, c, d) \sin \varphi(\tilde{X}) \\ 1 \end{pmatrix}, \quad \tilde{X} = RX + T
\]

Minimize the objective function \( J \) with respect to 13 parameters (6 for extrinsic parameters \((\omega, \kappa, \rho, t_1, t_2, t_3)\), 4 identifying the model \((a, b, c, d)\), \(\beta\), and \((u_0, v_0))\):

\[
J(\omega, \kappa, \rho, t_1, t_2, t_3, a, b, c, d, \beta, u_0, v_0) = \sum_{i=1}^{N} \left\| \tilde{u} - \mathbf{u}(\omega, \kappa, \rho, t_1, t_2, t_3, a, b, c, d, \beta, u_0, v_0) \right\|,
\]

where \( \mathbf{u}(\omega, \kappa, \rho, t_1, t_2, t_3, a, b, c, d, \beta, u_0, v_0) \) represents the points reprojected by the model and \( \tilde{u} \) stands for the point coordinates measured in the image.
Objective function minimization

Development of the value of the objective function during optimization. The errors are scaled 20 times.
Experimental results

Experimental setup and the reprojection error (the value of the objective function $J$). The arrows representing the error are scaled 20 times.
An application - the 360 x 360 mosaic

- Conventional cameras have **limited FOV**
- 360 x 360 mosaic covers 360° in **both horizontal** and **vertical** direction
An application - the 360 x 360 mosaic

- they are realized by moving a planar pencil of light rays $\pi$ on a circular path
- the pencil $\pi$ can be realized using the Nikon FC-E8 fish eye converter

Image acquired by a CCD camera

- Left eye mosaic
- Right eye mosaic

Diagram showing the 360 x 360 mosaic technique.
Conclusion

- Realization of the 360 x 360 mosaic with a fish eye lens was proposed.
- A model for the FC-E8 converter lens was derived.
- A calibration procedure was presented.
Planar retina
\((u,v,1)^T\)

Spherical retina
\((u,v,w)^T\)
Model fitting error [pixels] = $a \tan(\theta/b)$ + $c \sin(\theta/d)$
$z = \text{optical axis}$

$(x', y', z')$
Image acquired by a CCD camera

Left eye mosaic

Right eye mosaic