In-Situ Recession Measurements by Photogrammetric Ablator Surface Analysis

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Motivation

- Ablative material loss quantification with respect to surface recession.
- In-situ analysis of recession.
- Identification of influence of material defects.
- Analyse differences in ground testing compared to flight scenario.

Surface photography during test.
Theory

- Using the central projection, a 3D object point can be seen in two images.
- The needed information is the orientation of the sensor area (inner orientation) and the orientation of the camera in space (outer orientation).
- Connecting both images allows to derive where the lines overlap. This is the 3D position in space.
- More cameras increase the accuracy, because the overlap becomes more precise.

Central Projection: A 3D point $P$ is found as a $P'$ and $P''$ in the image data.
Experimental Setup

- Experiments in the plasma wind tunnel PWK1 at IRS.
- Two Canon EOS 60D DSLR cameras.
- Carbon preform material sample (Mersen) with a density of 0.18 g/cm³.
- Surface temperature measurement using Pyrometry and Thermography.
### Flow Condition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{m}_{\text{air}}$</td>
<td>18 g/s</td>
</tr>
<tr>
<td>$p_{\infty}$</td>
<td>16.6 hPa</td>
</tr>
<tr>
<td>$p_{\text{tot}}$</td>
<td>24.3 hPa</td>
</tr>
<tr>
<td>$P_{\text{el}}$</td>
<td>162 kW</td>
</tr>
<tr>
<td>$\dot{q}_{\text{coldwall}}$</td>
<td>4.1 MW/m$^2$</td>
</tr>
<tr>
<td>$h_{\text{local}}$</td>
<td>68.4 MJ/kg</td>
</tr>
</tbody>
</table>

### Camera Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length</td>
<td>300 mm</td>
</tr>
<tr>
<td>Resolution</td>
<td>17.9 MPix</td>
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<tr>
<td>Frame rate</td>
<td>3 fps</td>
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<tr>
<td>Exposure time</td>
<td>1/4000 s</td>
</tr>
<tr>
<td>Aperture</td>
<td>f/25</td>
</tr>
<tr>
<td>Filter</td>
<td>ND1.2</td>
</tr>
</tbody>
</table>

- Heat flux, total pressure, and enthalpy correspond to a hayabusa flight condition at an altitude of 78 km.
- Plasma wind tunnel flow is subsonic.
- The combination of ND filter and short exposure time gives sufficient surface feature resolution for the photogrammetry.
Calibration

- Three-dimensional object is positioned close to the measurement location.
- Pictures are taken for different object inclinations.
- Pictures are arranged by the software to calculate the camera orientation.
- Camera position must not be changed!

Camera Calibration using Agisoft.
Data Reduction

Surface Triangulation of the point cloud.

- The calibrated camera position is loaded in the software SURE.
- Acquired image pairs from plasma wind tunnel tests are analysed by SURE.
- SURE computes point positions from the image pair, so a 3D map is generated.
- The surface change is then identified from image pair to image pair.
Photogrammetric In-Situ Surface Analysis
Recession measurement

- Rate is derived from 3 sec., i.e. mean value of 9 frames.
- Rate is very constant.
- Mean rate (52.5 $\mu$m/s) is consistent with published values.
- Asymmetric recession due to sample holder.
Surface Analysis

- At the beginning the scratches are visible in photos and point cloud (upper figure).
- For later times (lower figure) scratch is only visible in point cloud.
- A lower recession has been measured, perhaps due to denser material, i.e. the scratch was probably a dent.
Summary

- Three-dimensional surface determination from stereoscopic image acquisition has been realized.
- Surface is resovled with 300 000 data points, i.e. 25 000 points/cm² (approx. 400 dpi).
- Recession rate has been derived from photogrammetric data sets to 52.5 µm/s for the carbon preform.
- Surface defects (scratches, dents) can be analysed.
Thank you.

Further questions, comments, ideas:

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...and thank you, Megan!