Profiling Turbulence using Dual Camera Time Lapse Imagery

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Abstract:
Accurate characterization of atmospheric turbulence is useful for performance assessment of optical systems operating in real environments. A method to estimate turbulence parameters, such as path weighted $C_n^2$ from turbulence-induced random motion, differential motion of point sources in the time-lapse imagery of a distant target is presented. Since the method is phase-based, it can be applied to longer paths. The approach uses a derived set of path weighting functions that drop to zero at both ends of the imaging path. Using differently separated point sources, a rich set of weighting functions can be obtained. These weighting functions can be used to profile the turbulence along the path. The dual camera time-lapse measurements can thus show different measurements of $C_n^2$ on different parts of the path. The method is applied to images captured along a path of varying materials, and the estimates are compared to Sonic Anemometers placed at certain points along the path.

Methods:
The test was conducted over a 511m path of varying material. The first 250m being concrete, the rest grass. See the path in figure 1. Data was collected at varying times of day on June 27th-28th and at night on July 25th. The imaging path was 1.5m above the ground. On the concrete end two FLIR cameras were set up 10 centimeters apart, seen in figure 3. They were operating on 10fps every 10 seconds. On the other end was a LED board with varying separations, shown in figure 2 as 300 frames, or 5min, averaged together. At every 100m along the path an ATI sonic anemometer, seen in figure 4 was set up to calculate $C_n^2$ at certain points along the path.

Data Processing:
Turbulence weighting functions for differential tilt variances between the two cameras due to pairs of LEDs of varying separations are shown in figure 5. Tilts were computed from centroids of individual LEDs by each camera over a 5min period. By generating a matrix, $M$, the rows are formed from the individual sampled weighting functions, and the columns then correspond to the range where these functions are sampled. $C_n^2$ can be calculated along the path using $C_n^2 = M^\dagger V$, where $M^\dagger$ is the pseudo-inverse of $M$ and $V$ is the set of measured differential tilt variances. In an attempt to reduce measurement noise different combinations of weighting functions were attempted.

Result:

Figure 6:

$C_n^2$ Profiles along the path were processed for varying times and days. The results can be seen in figures 6,7,8,9. The results are plotted with 3-4 sonic anemometer $C_n^2$ values in their corresponding position on the path marked with black diamonds. The imaging profiles match very well with the anemometer derived measurements. The influence function shows that the profile shows accurate values between 100m and 350-400m. Any error may be due to measurement noise, from poor image contrast or external motion, or due to numerical noise. A clear change in turbulence along the path is noticeable on each profile. Almost always showing a considerable rise of $C_n^2$ on the grass end of the path, this was also seen in the anemometers.

Conclusions:
A method for obtaining turbulence distribution along a path using two cameras and a LED array was described. A significant advantage of this method is that it is phase-based, and hence can be applied to long paths through turbulence where the irradiance-based techniques suffer from saturation problems. Turbulence profiles were generated by measuring the difference in tilts at a single camera or between cameras due to a pair of LED separations at varying separations. The wide variation in weighting functions give a good estimate of $C_n^2$ in between 100m-400m of a 511m path. The $C_n^2$ estimation along the path matched very well with the anemometer derived measurements.

Looking Ahead:
Future experiments involving dual camera time lapse imaging are focusing on extended patch sources as a target end over a path of varying altitude. Other extensions would involve future work in reducing motion on the cameras and increasing target source separations for better profiling near the aperture side.

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