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Anisoplanatic Electromagnetic Image Propagation through Narrow or Extended Phase Turbulence using Altitude-Dependent Structure Parameter

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Abstract: Imaging through turbulence gives rise to anisoplanatism (space-variant blur). The effects of turbulence on imaging are often modeled through the use of a sequence of phase screens distributed along the optical path. We have implemented the split-step wave propagation method focusing on turbulence-corrupted image measurements.

Keywords: turbulence, phase screen, Hufnagel-Valley, isoplanatic angle.

1. Background

The strength of turbulence along the propagation path is described by the structure parameter $C_n^2(h)$. There are several profiles that have been established to estimate $C_n^2(h)$. The most commonly used profile is The Hufnagel-Valley (HV) model [1]

$$C_n^2(h) = e^{(-\frac{h}{100})} + 5.94 \times 10^{-53} \times (\frac{v}{27})^2 h^{10} e^{(-\frac{h}{1000})} + 2\,.7 \text{ x } 10^{-16} e^{(-\frac{h}{15000})}$$

The parameter A represents the turbulence strength at ground level while v is the high altitude wind speed The most commonly used is the HV5/7 which sets $A = 1.7 \times 10^{-14}$ and $v = 21\, m/s$.

the C_n^2 profile can be break into a finite number of layers with individual $C_{n_i}^2$ and the value of the weight of the i^{th} layer W_i ,

where $W_i = C_{n_i}^2 \Delta z_i / I_C$ and $I_C = \int_0^L d_z z^m\ C_n^2(z) = \sum_{i=1}^4 z_i^m\ C_{n_i}^2 \Delta z_i$

z_i and Δz_i are the altitude and the thinness of the i^{th} layer . L is the length of the propagation path through turbulence and $0 \le m \le 7$. The four layer model is adequate for a wide range of imaging performance [2].

The seeing cell size is commonly called the Fired parameter , the Fried parameter for the i^{th}layer is given by:

$r_{o_i} = 0.185 \left[\frac{4\pi^2}{k^2\, C_{n_i}^2 \Delta z_i}\right]^{3/5}$ and the overall Fried parameter $r_0 = \left[\sum_{i=1}^4 r_{o_i}^{-5/3}\right]^{-3/5}$,where k is the wave number .

The final turbulence parameter to be addressed is the isoplanatic angle θ_0 is defined as the largest field angle over which turbulence can be accurately estimated

$$\theta_0 = \left[6.8794 L^{5/3} \sum_{i=1}^{n} r_{o_i}^{-\frac{5}{3}} (1 - \frac{z_i}{L})^{5/3}\right]^{-3/5}$$

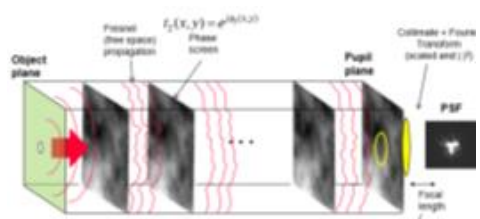


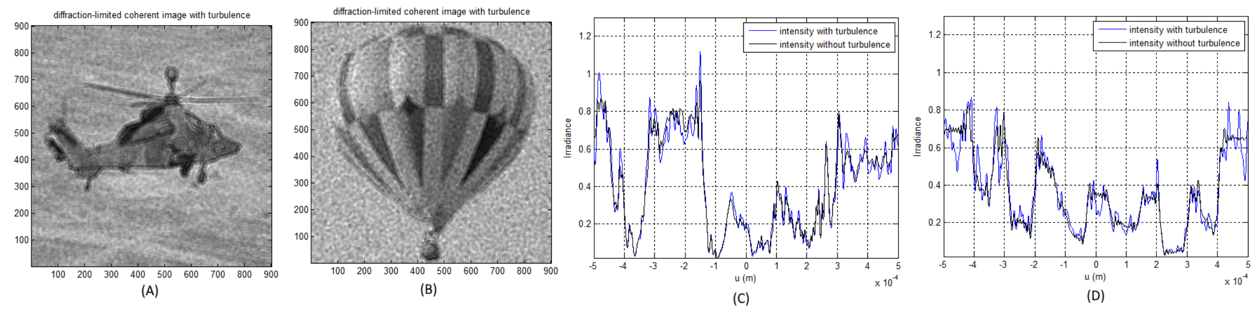
Fig.1. The simulated representation of turbulence model

2. Atmospheric model

In the proposed model, the PSD is calculated and used to characterize the phase screens. We use the Modified von Karman (MVK). The main idea is that we try to model the atmospheric turbulence effect to three objects at high $h_2 = 5km\,, 500m \text{ and } 100m$ while the image system placed at the earth at fixed place. For the three cases the propagation distance through the turbulence is $L = 6km$. Fig.(1) shows The simulated representation of turbulence model. We model a four layer model for turbulence such that turbulence layers are chosen to have uniform thickness. $\Delta z_i = L/4$. With simple math the high of each layer can be calculated. And the total Fried parameter for different object can be found after we find C_n^2 corresponding to the high using HV-21 model. The propagation distance through the turbulence equal to $L = 6km$ and the layers have uniform thickness where the wavelength used is $\lambda = 0.5$µm.

Target High	Layer 1 W_1	Layer 2 W_2	Layer 3 W_3	Layer 4 W_4	I_C $m^{1/3}$	Total r_0 cm	$\frac{D}{r_0}$
5km	0.9889	0.0068	0.0029	0.0013	2.598×10^{-11}	1.140	3.5
500m	0.7012	0.2080	0.0659	0.0247	3.691×10^{-11}	0.920	4.35
100m	0.3479	0.2721	0.2130	0.1669	7.444×10^{-11}	0.610	6.5

Table 1: Weights Wi's and total Fried parameter of each layer for different target high using HV-21 model.



3. Constant C_n^2 model

In this case, for different objects we assume C_n^2 fixed during the propagation path taken the value that belong to the middle high of then for 5km, 500m and 100m $C_n^2 = 5.1024 \times 10^{-17}$, 1.6239×10^{-15} and $1.0572 \times 10^{-14} m^{-2/3}$ respectively. And the corresponding r_0 values is 12.49, 1.57 and 0.51cm.

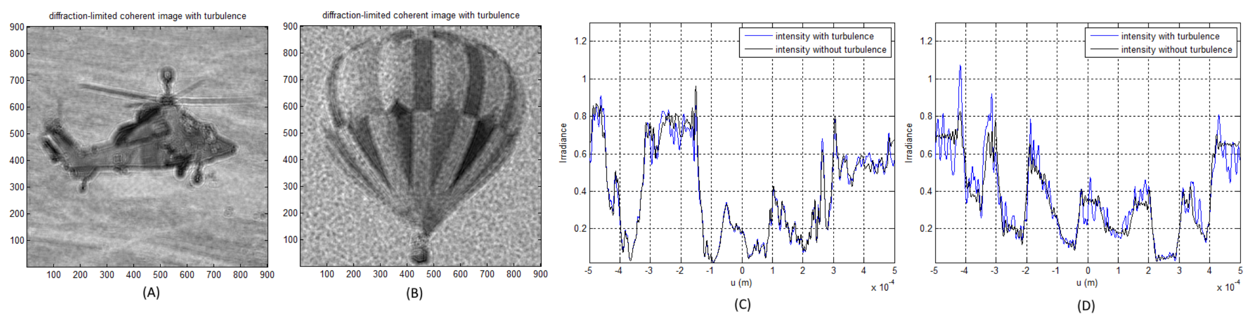


Fig.3. Simulator output for the object at (A). 500m (B) 100m .(C) and (D) Intensity Row profile of the images (A) and (B) respectively verse ideal image Corresponding to turbulence conditions fixed C_n^2

3. Conclusion

The results shows higher intensity distortion and variation as the object close to the ground in both models. However fixed C_n^2 model perform less accuracy comparing with the adequate model in table (1). It gives large r_0 difference when the object at 5km r_0 changes from 1.140 to 12.49cm . Also, performs less turbulence effects at 500m r_0 changes from 0.920 to 1.57cm as in Fig.(2,3).(A) and less intensity variation (Fig.(2,3) (C)) . For the object at high 100m, fixed C_n^2 model performs higher turbulence effects r_0 changes from 0.61 to 0.51cm as in Fig.(2,3).(B) as result, intensity variation in Fig.(3,D) increases comparing with Fig.(2,D).

4. References

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