Research on Multi-wavelength and Multi-beam Illumination for Improving Object Illumination Uniformity

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Abstract: The imaging and tracking to the far dim objects in the air are usually difficult for detecting system to get their clear images and accurate positions, due to the objects neither emitting light nor reflecting sunlight. Using active laser illumination technology, the target will be illuminated and the echo intensity of target can be increased. The laser intensity spatial distribution on the target plane fluctuates usually remarkably due to the atmospheric turbulence and other causes, which will decrease image resolution and tracking accuracy in optical system. In this paper, we presented a method of using illumination with the supercontinuum spectrum laser beam combination to improve the effect of target illumination uniformity. As the atmosphere transmittance ratios differs with wavelength, we set up a multi-wavelength and multi-beam target illumination simulation system to represent the supercontinuum spectrum laser illumination effect. As the previous simulation results and the experimental results, which both reflect an improving effect of illumination uniformity significantly by increasing of the beam number. The illumination uniformity of single beam with multi-wavelength spectrum components was analyzed, and the simulation results of one single beam, three beams and six beams with 9 wavelength spectrum were compared, which showed that the illumination uniformity in target plane was improved with both the number of wavelength spectrum components and the number of beams increasing. It showed that multi-spectral multi-beam illumination had great advantages in improving illumination uniformity and the supercontinuum laser can be a good active illumination source.

1 INTRODUCTION

The imaging of and tracking to the far dim objects in the air are usually difficult for detecting system to get their clear images and accurate positions, due to the objects not emitting light or reflecting sunlight. Using active laser illumination technology, the target will be illuminated and the echo intensity of target can be increased. Active illumination with multi-beam has been proved to be an effective technology to improve the object illumination uniformity (Pavel et al., 2007) (Quan et al., 2013) which can increase object image resolution and tracking accuracy in optical system. Supercontinuum (SC) laser sources have advantages of wide spectrum range and good spatial coherence, high brightness, better in direction. With the increasing of the average output power (Song et al, 2013) (Xia et al, 2009), they become practicable in many application areas, such as laser communication, laser remote sensing, hyperspectral LiDAR, and laser ranging (Alexander et al, 2012) (Hakala et al, 2012). These applications all require SC laser sources propagate through the atmosphere, meaning that the beam will suffer atmospheric absorption, refraction, extinction and turbulence effect (Kang and Wenyue, 2015) (Wuming et al, 2014). The wide spectrum of SC laser propagating through atmosphere will be separated into several main wavelength bands due to the transmittance of different wavelengths. We use SC laser as active illumination source means only the wavelength bands which have high transmittance can be valid for illuminating object. In this paper, we presented a method of using the SC laser beams combination as active illumination source to improve the effect of target illumination uniformity. We set up a multi-wavelength and multi-beam atmospheric propagation and target illumination simulation system. The simulation results showed that multi-spectral multi-beam illumination had great advantages in improving illumination uniformity.

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2 ESTABLISHMENT OF SIMULATION SYSTEM

As a numerical example, we chose the SC laser spectrum rang from 600nm to 1700nm (Chen et al, 2011) and the power spectrum density with average output power. The transmittance of the atmosphere is calculated by MODTRAN software (Berk et al, 2014). The calculation was carried out under the typical atmosphere situations: mid-latitude summer, rural aerosol model with 23km visibility and CO2 mixing ratio 360ppm. The distance of laser propagation path is 100km. The transmittance $T_0(\lambda, z)$ for different wavelengths is depicted in Figure 1.

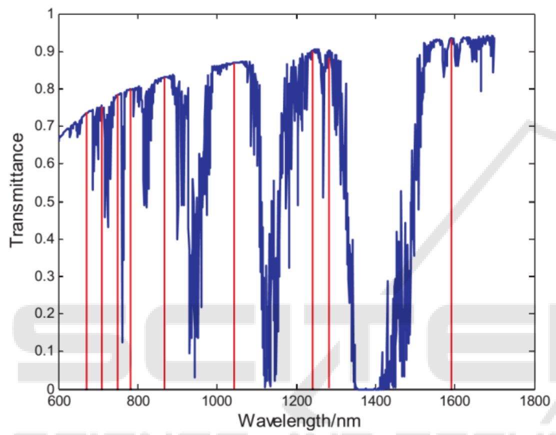


Figure 1: Transmittance in different wavelengths.

The simulation system is built in SeeLight, a software tool for high fidelity modeling of advanced optical systems such as laser active illumination and object detection systems which is developed by National University of Defense Technology and Institute of software, Chinese academy of Sciences. The principle of the software is based on wave optics theory with performing propagation by the angular spectrum theory and fast Fourier transform. Figure 2 shows the multi-beam (taking six beams for instance) and multi-wavelength active illumination simulation system schematic. The number of beams can be changed in simulation system by adding or deleting laser source modals. And the beam spatial arrangement is cycle type. Each beam contains several wavelengths. We chose 9 typical wavelengths which had high transmittance ratios marked with red lines in Fig.1 for each beam. The data of coherence lengths and transmittance ratios was shown in Table 1. In atmosphere propagation path modal, turbulence layer was represented by a phase-changing screen with the associated transverse wind velocity V. The turbulence strength was decided by refractive index fluctuation function Cn^2, we used HV57 modal with average Cn^2 value of 10^{-16} to present moderate turbulence intensity. At the same turbulence intensity, different wavelength beam experienced different coherence length R0 as shown in Table 1. With the same transmitter diameter of each beam (20cm), different wavelength beam would undergo different turbulence influences.

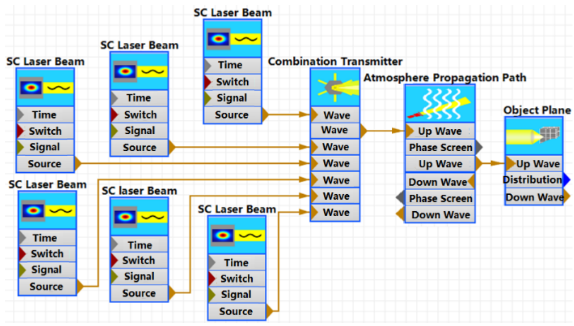


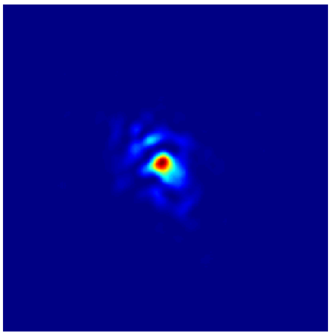
Figure 2: The simulation model schematic of Multi-beam active illumination was built in SeeLight software.

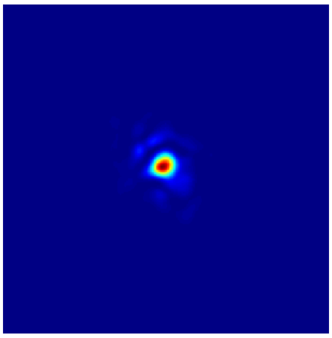
Table 1: The coherence lengths of 9 typical wavelengths with high transmittance ratios.

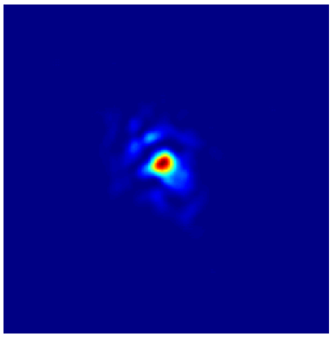
	Wavelength(nm)	Transmittance	R0(cm)
1	670	75.5%	4.4
2	710	75.9%	4.7
3	750	79.1%	5.0
4	810	79.5%	5.5
5	880	85.9%	6.1
6	1060	88.7%	7.7
7	1250	91.8%	9.4
8	1290	89.3%	9.7
9	1600	91.2%	12.6

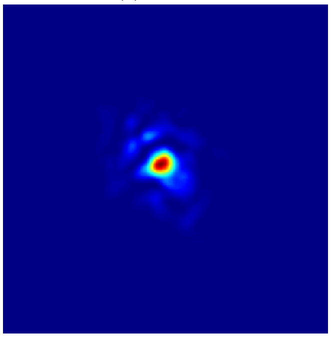
3 SIMULATION RESULTS

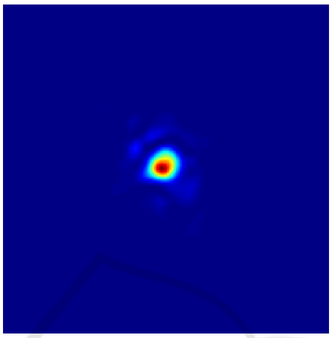
Each multi-wavelength beam propagated through different turbulence area as they distributed over different situation at the exit of transmitter and their propagation paths differ to each other. Each wavelength in same beam propagated through the same atmosphere path and interacted with the same turbulence, but they experienced different transmittances and coherence lengths. Fig.3 showed the 9 different wavelength beams far field intensity distributions after propagation through moderate turbulence. From Figure 3 (a) to (i), the far field spot turned to be more concentrated and bigger size, which meant longer wavelength beam suffered less turbulence distorted.

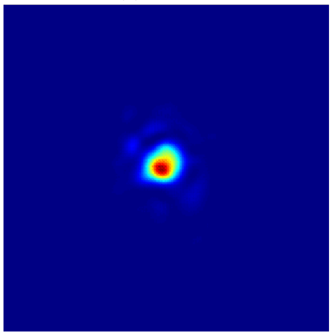

(a) 670nm

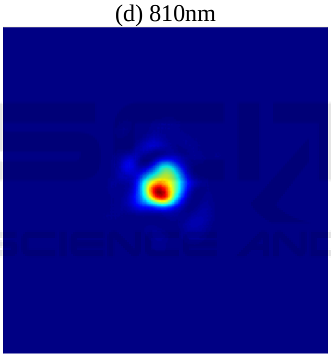

(b) 710nm

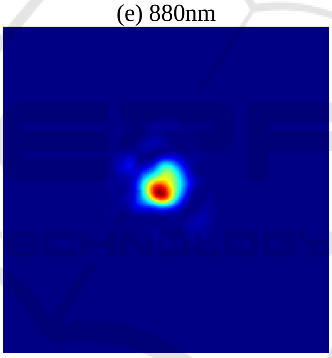

(c) 750nm


(d) 810nm


(e) 880nm


(f) 1060nm


(g) 1250nm


(h) 1290nm

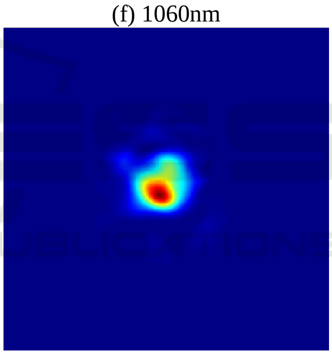

(i) 1600nm

Figure 3: The different wavelength beams far field intensity distributions.

Figure 4 showed the long exposure far field spot of one multi-wavelength beam with 9 typical wavelength components propagating to the object plane. Compared with each wavelength far field spot in Figure 3, we can draw the conclusion that the multi-wavelength SC laser illumination can make better illumination uniformity than single wavelength laser illumination.

In our previous work (Quan et al, 2013), we have already proved that multi-beam illumination could make better illumination uniformity than one beam and the larger number of beams could produce the better uniformity. In this paper, we also simulated multi-beam lasers with multi wavelength components illumination system as shown in Figure 2. Three beams and six beams separately combined together as illumination sources to simulate the illumination

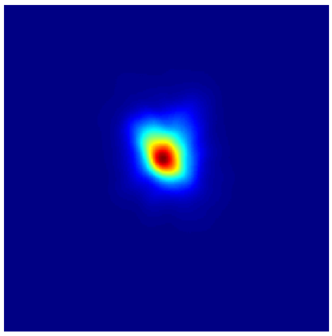
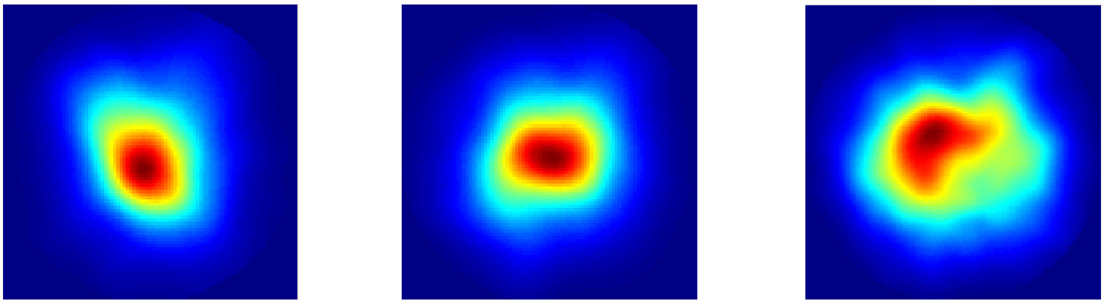


Figure 4: The long exposure far field spot of one multi-wavelength beam.

effect. The simulation results presented in Figure 5 show the calculated far field spots intensity of the 86.5% power in bucket of one beam, three beams and



(a) one beam (b) three beams (c) six beams

Figure 5: The far field spots intensity of the 86.5% power in bucket.

six beams. The spot intensity RMS of one beam, three beams and six beams were 39, 31 and 19 separately. The illumination uniformity showed a good improvement with the beam number increasing.

We also got the spot intensity RMS of one beam, three beams and six beams simulated at other atmosphere conditions with different Cn^2 values. Table 2 showed the calculated RMS of far field spots were all reduced at different turbulence intensity from average Cn^2 of 10^{-15}, 10^{-16} to 10^{-17}.

Table 2: The far field spots RMS data of one beam, three beams and six beams at different turbulence intensities.

	$Cn^2=10^{-15}$	$Cn^2=10^{-16}$	$Cn^2=10^{-17}$
1 beam	45	39	35
3 beams	35	31	28
6 beams	24	19	17

4 CONCLUSIONS

In this paper, we have presented a method of using the super-continuum spectrum laser beam combination to improve the illumination uniformity in atmosphere propagation. As the atmosphere transmittance ratios differs with wavelength, we set up a multi-wavelength and multi-beam laser illumination simulation system to represent the SC laser illumination effect. The simulation of multi-beam illumination was carried out to analysis the number of the illumination beams on the influence of illumination uniformity under different atmospheric conditions. The illumination uniformity of one single beam, three beams and six beams with 9 high transmittance ratio wavelength spectrum were compared, which showed that the illumination uniformity in target plane was improved with both the number of wavelength spectrum components and the number of beams increasing. The spot intensity RMS of one beam, three beams and six beams were all reduced at different turbulence intensities. The simulation results showed that multi-spectral multi-beam illumination had great advantages in improving illumination uniformity. With high illumination uniformity at target end, the echo intensity of the objects will be more uniformity, which will improve the profile definition of targets. The detecting system could get their clear images and accurate positions with SC laser illumination.

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