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Calculation of the attenuation of infrared laser beam propagation in the atmosphere

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Abstract

The atmospheric attenuation of laser beam due to the scattering by the atmospheric particle such as fog, mist, and haze or dust has been calculated as a function of visibility (visual range).the theoretical results show that the laser wavelength in the near infrared region 1.8µm have attenuation more than middle infrared regions, 3.11 µm and far infrared region 8.5µm although these wavelengths have transmittance windows, also these result show that, in fog condition where visibility is less than 0.5km, the atmospheric attenuation of laser beam is independence of laser wavelength . These results are obtained for horizontal path and confirmed by comparison with published data.

في هذا البحث تم حساب التوهين الجوي لحزمة الليزر نتيجة استطار تها بجسيمات الجو مثل الضباب الكثيف و الخفيف والأتربة الجوية كدالة للوضوحية (مدى الرؤيا). النتائج النظرية أظهرت إن الأطوال الليزرية الواقعة في المنطقة تحت الحمراء القريبة8.1µm. تملك توهين جوي أكثر من الأطوال الليزرية الواقعة في المنطقة تحت الحمراء المتوسطه 3.11 µm والبعيدة 8.5 µmعلى الرغم من ان هذه الأطوال تمتلك نوافذ جوية.كذالك تبين ان حالة الضباب الكثيف جدا حيث تكون الوضوحية اقل من، 0.5km فان التوهين الجوي لا يعتمد على الطول ألموجى بل يلازم قيم ثابتة معتمد

على الوضوحية فقط هذه النتائج حسبت للمسارات الأفقية للحزمة الليزرية وقد أظهرت هذه النتائج توافق مع البيانات والنتانج المنشورة.

1-introduction

Knowledge on propagation infrared laser beam in the atmosphere is required for many purposes such as optical communication, earth resources remote sensing, laser guidance weapons and laser range tinder.

The transmission of electromagnetic wave through the atmosphere is governed by the attenuation due to both scattering and absorption by all the atmospheric species present in the path of propagation. The atmospheric path is categorized to horizontal path (constant pressure) and(change pressure)(1.5) the absorption occurs by water vapor, slant path carbon dioxide, ozone. nitrous oxides, carbon monoxide, nitrogen and oxygen, while the scattering is produced by gas molecules, dust, smoke, fog and rain(2.5) .The earth's atmosphere is surrounded by number of layers, each layer is characterized by (pressure, density, and temperature) and these properties of layers are variable with time and location .The transparency of the atmosphere for laser radiation is one of the most important parameters in the calculation of the attenuation. This is depending on the weather and the path length (range) .

2-Theoretical model

The attenuation of laser beam through the atmosphere is described By exponential Lambert law{2,3,6,7} .

$\tau_R = P_R / P_0 = e^{-\alpha R}$ …………(1)

Where τ_R = Transmittance at ranger (R)

P_R = Laser power at range (R)

P_0= Laser power at the sources

α = Total attenuation coefficient per unit length The total attenuation coefficient is given by:

$\alpha = s + k$ ....(2)

Where k = absorption coefficient

S = scattering coefficient

The contribution of absorption coefficient to The total attenuation is very small special for infrared laser beam, therefore the effects of scattering dominate the total attenuation coefficient{6,7} The type of scattering is determined by the size of the atmospheric particle with respect to the laser wavelength. The size of the atmospheric particle described by a dimensionless number called size parameter(a){3}

$\alpha = 2\pi r / \lambda$ ....(3)

Where r = radius of scattering particle

λ = Laser wavelength

The general relation between wavelength and scattering coefficient is{3,6,11}

$S_\lambda = d\lambda^{-q}$……..(4)

Where: d = constant parameter

q = a parameter whose value depends on type of scattering

There are three type of scattering occurs in the atmosphere, Rayleigh , Mie and Non-selective or Geometrical scattering Rayleigh scattering occurs when wavelength is much Larger than the particle size ($\lambda \gg r$)in this kind of scattering (q) is Equal to 4 such scattering would be present even in completely clear atmosphere, because the gas molecules themselves would scatter the radiation. the effect of Rayleigh scattering on the total attenuation is very small, so it can be neglected{3,6,10} .

As the particle size approaches laser wavelength ($\lambda \approx r$), scattering of radiation off the larger particles becomes more dominate in the forward direction as opposed to the backward direction. this type of scattering, where the size parameter (a) varies between (0.1, 50) such as fog, smoke, haze and dust is called Mie scattering , where the value of q varies from (0 to 1.6)[3,6] The third generalized scattering occurs when the atmospheric particles are much larger than laser wavelength ($r >> \lambda$) size parameter grater than 50, the scattering is called Geometrical or Nom-selective scattering, the scattering particles are larger enough so that the angular distribution of scattered radiation can be described by geometric optics .the Rain drops ,snow, hail, cloud droplets and heavy fogs are caused Geometrical or Nom-selective scattering of laser wavelength . the scattering is called Nom-selective because there is no dependence of the attenuation coefficient on laser wavelength ,where the value of (q) equal Zero[3,6] .

3- Methods of calculation

According to general equation (4) an empirical relation often used to calculate the atmospheric attenuation in term of visibility (visual range) and wavelength this relation is[2,3,4,6] .

$S = 3.92 / \nu \, (\lambda / 0.55)^{-q}$………(5)

Where : λ =wavelength in micrometer (μm)

ν = visibility (visual range) in kilometer (Km) .

S = atmospheric attenuation caused by scattering(l/km).

q = the size distribution of the scattering particles

q =1.6 for high visibility (v > 50km). .... (5- a).

q =1 .3 for average visibility (6km< v <50km)... (5- b).

q =0.585 $^3\sqrt{v}$ 3 for low visibility (v < 6km)...........(5- c).

The visibility (v) is defined as the path length at which transmission at 0.55μm wavelength (where the sensitivity for the light adapted human eye peak). is 2%, this is intended to correspond to the distance at which a block object can just be discerned against the horizon sky, therefore for $R = \nu$ we have τ = 0.02 According to equations (4 and 5) the value of (q) is very important because it determines the wavelength dependence of the the type of scattering[5,6,7]

A search in literature agrees with equation (5) but the value of (q) at 1aW visibility equation (5-c) might in error. in fact there is strong empirical data which suggests for the value of (q) when the visibility is less than (6km).Eldridge denied three generalized types of zonesof shorter visibility as range , weather fog for visibility less than (0.5 km) , haze for visibilities greater thane (l km) and transitional zone called mist for visibilities between (0.5 km and l km).these zones are based on changes in observed particle size distributions and changes in the wavelength selectivity of measured attenuation coefficients which have mentioned previously.

Then the expression for (q) in equation (5-c) is [3,4].

$q = 0$ for fog ($v < 0.5$ km) …...(6-a)

$q = v - 0.5$ for mist (0.5 km $< v <1$km)........ (6-b)

$q = 0.16 v + 0.34$ for haze (l km $< v < 6$km)....... (6-c)

Where (v) is the visibility in km.

Aldridge indicates that haze is primarily made of microscopic fine dust or salt or small water dropt on the order of a few tenths of a micron. fog occurs during very high relative humidity when water droplets of a few microns to a few tens of microns from over the haze particle. Mist occurs during the transition from haze to fog as the humidity increases to saturation [3,4]

The unit that is used in this research to measure the attenuation is Decibel per unit length, from equation (1) the Decibel unit (dB) is defined as [9]

$$\tau_R = 10\, Log_{10}\, P_R/P_0 = (10 Log_{10} e)\alpha R = 4.34\alpha R = 4.34\tau_R$$

To make the attenuation in Decibel per unit Length multiply equation (5) by factor (4.34) [2] Theoretically by using (VISUAL-BASIC) Program figure (1) the atmospheric attenuation of laser beam has been calculated.

4-lkesults and discussion

The decibel loss per kilometer for different visibility condition in Table (1) derived from the attenuation coefficient calculated using Equation (5) From figure (1) It can be noted that the energy loosing from bathe laser beam through the atmosphere decreases with Increasing the visibility, where the visibility represents the weather conditions, this means there is a visual range which is related to weather condition specially related to radius and distribution of the atmospheric particles the weather condition that is considered for calculation the atmospheric attenuation is general not limited to a geographic location and the beam propagate horizontally with one layer In the atmosphere ,where this layer have same optical properties (refraction index) all wavelength also have other properties such as pressure temperature It can be concluded from table (1) that the atmospheric attenuation at a given visibility value decreases with increasing the wavelength, for example at visual range (1km) the attenuation for (1.8μm) wavelength is (9.38dB/km) While for (8.5μm) is (4.31 dB/km). These results can be gained according to Plank law{8,10,11}.

$E = h\nu = hc/\lambda$ ………(7)

Where E = energy of photon

v = frequency of phonon

c = velocity of light

According to equation (7) the energy that is carrying by the wavelength (8.5μm) is essentially less than the energy that is carrying by the wavelength (1.8μm), therefore the attenuation for near infrared regions 1.8μm is more than middle infrared regions 3.11 μm and far infrared region 8.5μm although these wavelengths have transmittance windows. These results also agree with Plank law.

Also from figure (2) it can be seen that, in fog condition where the visibility is less than (0.5 Km) the atmospheric attenuation take the same value for different laser wavelength because the value of (q) parameter equal zero Equation (6-a), therefore the atmospheric attenuation is independent on wavelength.

5-conclusion

l- The contribution of absorption coefficient to the total attenuation is very small specially for infrared laser beam; therefore the effects of scattering dominate the total attenuation coefficient.

2-in fog condition where the visibility is less than (0.5 Km) the atmospheric attenuation takes the same value for different laser wavelength, therefore the atmospheric attenuation is independent on the wavelength.

3-By using this theoretical model the atmospheric attenuation caused by scattering can be calculated for different laser wavelengths and different visibilities also we can calculate the atmospheric transmission for different given ranges.

References

(1) Cooke C.R "Automatic Laser Tracking and Ranging System" applied Optics, vol.! 1, no.2, 1972.

(2) Chimelis TV "Extinction of CO2 Laser radiation by fog and rain" applied optics, vol: 21, no: 18, 1982.

(3) Kim 1.1., B. McArthur and E. Korevaar, "Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communicationsy" Proc. SPIE, 4214, 26-37, 2001.

(4) Kim 1.1, Isaacs Schuster and E. Korevaar "Wireless optical transmission of fast Ethernet and ESCO Protocol data using the Terralink laser communication system" Society of photo-epical Instrumentation Engineerinplgg8.

(5) Al Naboulsi M., Sizun H. , F. de Fornel " Propagation of optical and infrared waves in the atmosphere" Journal SPIE International S i t for Optical Engineering, 2003.

(6) Forrester, P.A"Review laser range finder "optical and quantum electronics, vol.13,1981

(7) Al-Azawi war "Atmospheric transmission and aerosols 1 modulation transfer function from thermal imaging band" college or education lbn-All-lalthem, university Of Baghdadtreport), 2002.

(8) Jenkins. Far and .White "Fundamental of Optics"book, 1981.

(9) Donati, S "Photo detectors Devices, Circuits, and application's book , 2000.

(10) E.D.Hinkely" Laser Monitoring of the Atmosphere" (Topics in

Applied Physics, vol. 14) springer-verlay, 1976.
(11) Strohbehn "Laser Beam Propagation in the atmosphere", (Topics in Applied Physics, vol. 25), ch. (1,2,5,7) springer-verlay, 1978.

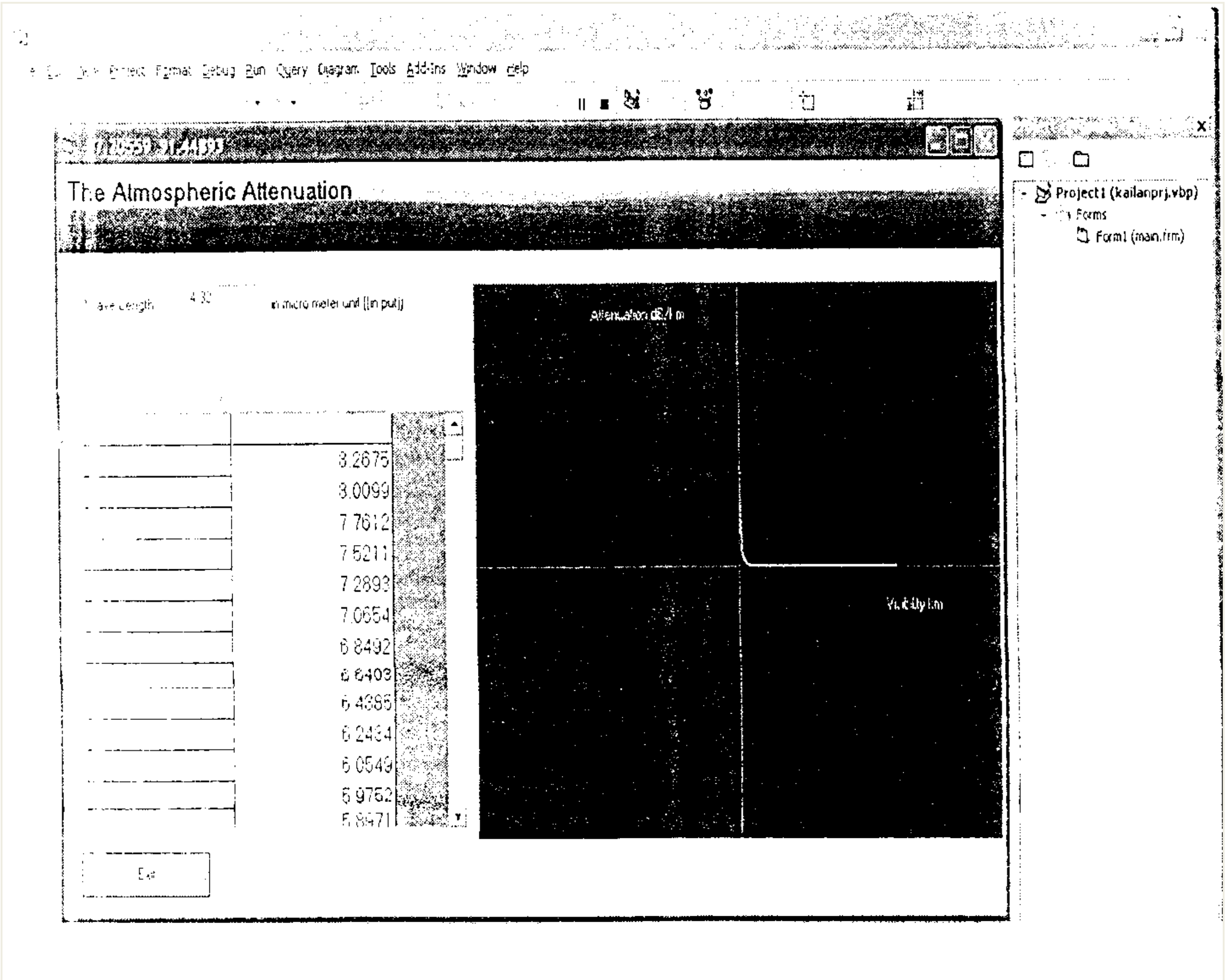

Figure (1) The executive view of tlw (VISUAL-BASIC) Program used calculate the atmospheric attenuation for different laser wavelength as data input in micrometer (μm) the Visibility (V) in (Km) and Attenuation (S) in (dB/Km) .

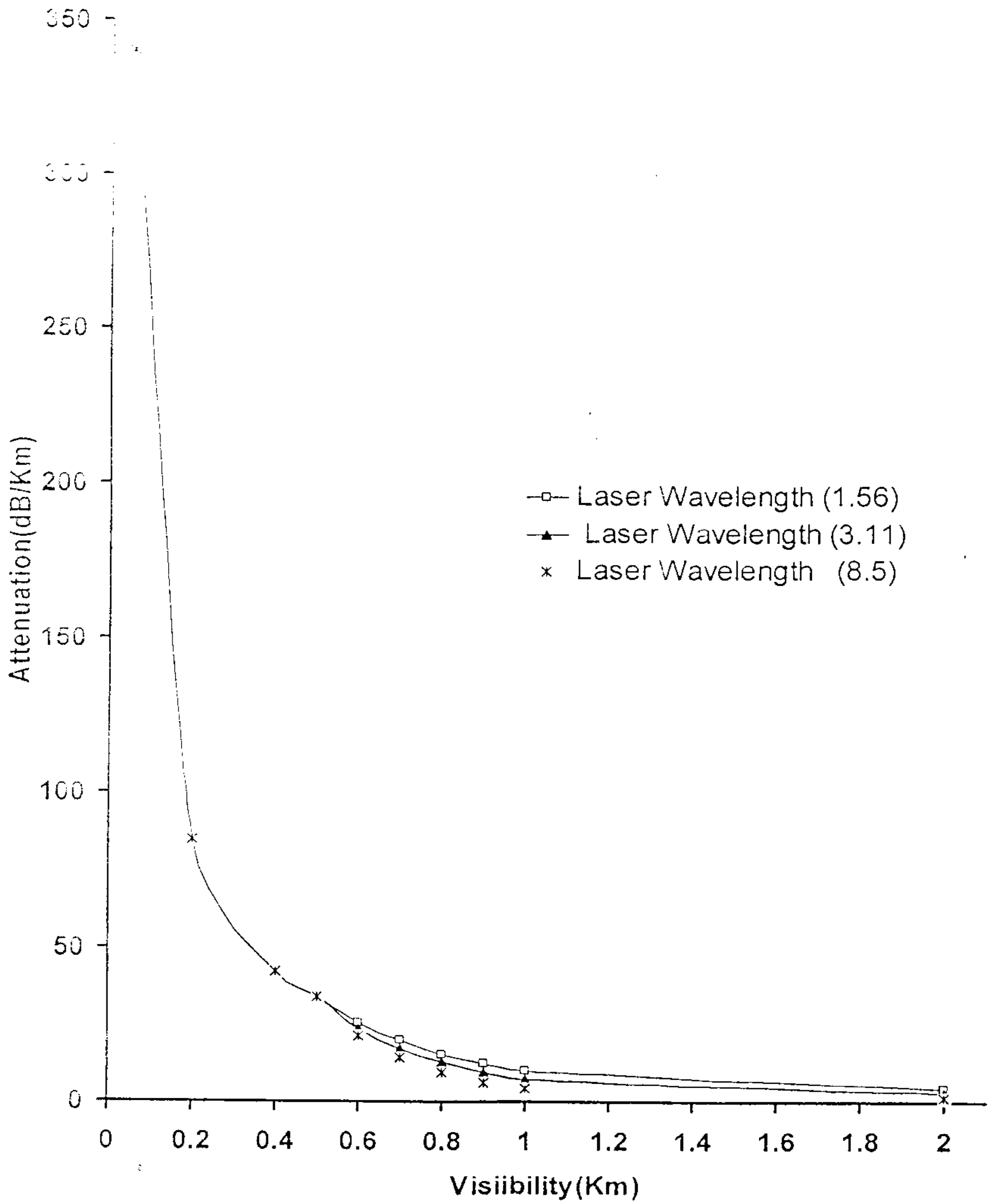

Figure (2) Atmospheric attenuation as a function of the visibility for different laser wavelength.

Table (1) A atmospheric attenuation in (dB/km) as a function of visit. Lie for difference laser wavelengths .

Visibility (Km)	Atmospheric attenuation(dB/Km)						Weather condition
	λ=1.56 (μm)	λ=1.8 (μm)	λ=3.11 (μm)	λ=4.32 (μm)	λ=8.5 (μm)	λ=10 (μm)	
0.01	1696.94	1696.94	1696.94	1696.94	1696.94	1696.94	fog (10-20) μm Radius
0.02	848.47	848.47	848.47	848.47	848.47	848.47	
0.04	424.23	424.23	424.23	424.23	424.23	424.23	
0.05	339.38	339.38	339.38	339.38	339.38	339.38	
0.2	84.84	84.84	84.84	84.84	84.84	84.84	
0.4	42.42	42.42	42.42	42.42	42.42	42.42	
0.5	33.93	33.93	33.93	33.93	33.93	33.93	
0.6	25.48	25.12	23.78	23.01	21.50	21.16	Mist (1-2) μm Radius
0.7	19.67	19.12	17.14	16.05	14.02	13.57	
0.8	15.51	14.86	12.61	11.42	9.32	8.88	
0.9	12.42	11.73	9.42	8.26	6.30	5.90	
1	10.07	9.38	7.13	6.05	4.31	3.97	
1.5	6.17	5.68	4.14	3.42	2.31	2.10	Haze or Dust (0.01-2) μm Radius
2	4.26	3.87	2.14	2.17	1.39	1.25	
2.5	3.13	2.82	1.88	1.47	0.89	0.76	
3	2.40	2.13	1.36	1.04	0.59	0.52	
3.5	1.89	1.66	1.01	0.75	0.41	0.35	
4	1.52	1.32	0.77	0.56	0.29	0.24	
4.5	1.24	1.07	0.60	0.42	0.20	0.17	
5	1.03	0.87	4730	0.32	0.14	0.12	
5.5	0.86	0.78	3730	0.24	0.15	0.08	
8	0.54	0.45	0.22	0.14	0.060	0.045	Clear
10	0.43	0.36	0.17	0.11	0.048	0.039	
14	0.31	0.25	0.12	0.083	0.034	0.027	
24	0.18	0.15	0.074	0.048	0.020	0.016	
50	0.087	0.072	0.35	0.023	0.00097	0.0078	Very clear
54	0.059	0.047	0.019	0.011	0.004	0.003	
58	0.055	0.44	0.018	0.0108	0.0037	0.0028	
60	0.053	0.042	0.017	0.0105	0.0035	0.0027	