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5 authors, including:

Jacek Wojtanowski
Military University of Technology

Marek Zygmunt
Military University of Technology

Mirosława Kaszczuk
Military University of Technology

Michal Muzal
Military University of Technology

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Comparison of 905 nm and 1550 nm semiconductor laser rangefinders' performance deterioration due to adverse environmental conditions

J. WOJTANOWSKI*, M. ZYGMUNT, M. KASZCZUK, Z. MIERCZYK, and M. MUZAL

Institute of Optoelectronics, Military University of Technology, 2 Sylwestra Kaliskiego Str., 00–908 Warszawa, Poland

Laser rangefinder performance (i.e., maximum range) is strongly affected by environment due to visibility-dependent laser attenuation in the atmosphere and target reflectivity variations induced by surface condition changes (dry vs. wet). Both factors have their unique spectral features which means that rangefinders operating at different wavelengths are affected by specific environmental changes in a different way. Current state of the art TOF (time of flight) semiconductor laser rangefinders are based mainly on two wavelengths: 905 nm and 1550 nm, which results from atmospheric transmission windows and availability of high power pulsed sources. The paper discusses the scope of maximum range degradation of hypothetical 0.9 μm and 1.5 μm rangefinders due to selected water-related environmental effects. Atmospheric extinction spectra were adapted from Standard Atmosphere Model and reflectance fingerprints of various materials have been measured. It is not the aim of the paper to determine in general which wavelength is superior for laser range finding, since a number of criteria could be considered, but to verify their susceptibility to adverse environmental conditions.

Keywords: laser rangefinder, atmospheric extinction, reflectance coefficient.

1. Introduction

Laser rangefinder maximum achievable range is related to numerous factors [1–3]. Some of them are hardware-related and can be modified during design process and others are imposed by local time-dependent environmental conditions, which cannot be controlled in any way. The final net effect is seen by the detection circuitry where optical echo power transformed into electrical signal and all optical and electronics noise additives produce a given signal-to-noise ratio (SNR). Basic formula includes inherent noise sources strictly associated with detection process:

– shot noise resulting from quantum nature of optical signals,
– dark current fluctuations noise,
– thermal noise (semiconductor/cathode excitations, carrier movements in circuitry).

In most near-infrared compact laser rangefinders, avalanche photodiodes (APD) are applied as detectors due to their internal signal multiplication, which results in overall high sensitivity. In such configuration signal-to-noise ratio is provided by the following range-resolved formula [4]

$$SNR(R) = \frac{P(R)S_\lambda M}{\sqrt{2eB[(P(R)+P_B)S_\lambda + I_d]M^{2+x} + \dfrac{4kTBF}{R_0}}}, \quad (1)$$

where: $P(R)$ is the optical echo power received as a return from the target, S_λ is the detector sensitivity, M is the multiplication gain factor, e is the electron charge, B is the electronic bandwidth required to process short echo pulses, P_B is the background light optical power collected by the detector, I_d is the detector dark current, x is the excess noise factor, k is the Boltzmann constant, T is the absolute temperature, F is the amplifier noise factor, R_0 is the load resistance.

Numerator of the above ratio can be perceived as a signal current and the denominator – as a noise current, respectively. Optical echo power [Eq. (1)] received as a return from the target is provided by a classical rangefinder equation [5]

$$P(R) = P_0 \rho \frac{A_0}{\pi R^2} \eta_0 \exp(-2\gamma R), \quad (2)$$

where: P_0 is peak output power of transmitted laser pulse, ρ is the target reflectivity coefficient, A_0 is the receiving aperture area, γ is the atmospheric extinction coefficient, η_0 is the receiving optics spectral transmission. Eq. (2) is valid when certain simplifications can be accepted

– atmospheric extinction does not vary significantly along measurement path (relatively horizontal measurements),
– laser spot is smaller than the target,
– target has lambertian-reflectance surface,
– target's surface is perpendicular to laser beam (measurement direction).

*e-mail: jwojtanowski@wat.edu.pl

Equations (1) and (2) both indicate no wavelength dependence since for any specific laser source one can assume nearly monochromatic regime. In general multi-band approach, it should be noted that environmental factors, i.e. atmospheric extinction coefficient, target reflectivity and ambient illumination background all depend on optical frequency.

The lowest level of signal-to-noise ratio (SNR_{min}) which can be properly evaluated by range calculating algorithms relates to the a.m. maximum measurable distance. It needs to be mentioned that due to high (kHz) repetition rate of semiconductor laser pulses, *SNR* is typically increased by summing up the echo signal responses from *N* laser shots, which results in $N^{1/2}$ improvement of SNR [4]. This integration technique is limited by target stability and maximum single measurement time period which in most cases of hand-held rangefinders should not exceed a few hundred milliseconds. SNR_{min} at the level of about 10 (ten) provides sufficient level of the input for typical algorithms. Merging Eqs. (1) and (2), maximum range measurement corresponds to the following equation

$$\frac{P(R_{max})S_\lambda M}{\sqrt{2eB[(P(R_{max})+P_B)S_\lambda+I_d]M^{2+x}+\frac{4kTBF}{R_0}}}=SNR_{min},\quad(3)$$

where R_{max} is the maximum theoretical measurable range. Assigning $P(R_{max})$ as P_{min}, one can solve Eq. (3) to obtain the analytical formula describing P_{min} as a function of SNR_{min}

$$P_{min}(SNR_{min})=\frac{SNR_{min}^2 eBM^{x+1}+SNR_{min}\sqrt{(SNR_{min}eBM^{x+1})^2+2eB[P_BS_\lambda+I_d]M^{2+x}+\frac{4kTBF}{R_0}}}{S_\lambda M}\quad(4)$$

which for a given SNR_{min} and rangefinder/environmental parameters assign unambiguously minimum required optical power of the echo signal impinging onto the detector surface, which still produce the proper range evaluation. This power corresponds to a certain maximum range also in an unambiguous way [Eq. (2)], so one can state that maximum range can be seen in terms of minimum signal-to-noise ratio SNR_{min} or equivalently in terms of minimum power P_{min}.

Taking into account changing atmospheric extinction and target reflectivity, the maximum measurable range changes as well, however, the minimum detectable power level P_{min} remains the same. For any given configuration of a selected rangefinder and two distinctive environmental conditions, concerning maximum range measurement, one can write

$$P_{min}^{(1)}=P_{min}^{(2)}\Rightarrow\rho^{(1)}\frac{\exp(-2\gamma^{(1)}R_{max}^{(1)})}{R_{max}^{(1)\,2}}=\rho^{(2)}\frac{\exp(-2\gamma^{(2)}R_{max}^{(2)})}{R_{max}^{(2)\,2}},\quad(5)$$

where: $^{(1)}$,$^{(2)}$ refer to the 1-st and 2-nd reflectivity/extinction configurations, respectively.

Equation (5) is valid only if background illumination level remains the same, which is assumed in the presented analysis. In order to determine the environmental impact on range, the direct range degradation factor $K_{1\to2}$ will be introduced, as the ratio of maximum theoretical distances at two reflectance/extinction variants

$$K_{1\to2}=\frac{R_{max}^{(2)}}{R_{max}^{(1)}}.\quad(6)$$

Due to the form of Eq. (5), Eq. (6) cannot be calculated analytically. The numerical analysis was performed to evaluate the problem. From Eq. (5), one can state, however, that the evaluation of range degradation can be developed totally apart from numerous rangefinder parameters and SNR, limiting analysis to reflectivity and extinction variation.

2. Water-related impact on rangefinders operation

The environmental content of water is associated both with atmospheric transmission of laser radiation [6,7] and target reflectivity of the targets [8]. The general rule states that both increased levels of air humidity and larger amount of water on reflecting surfaces of measured targets decrease the rangefinders performance which results mainly from strong water absorption in NIR (Near Infrared) spectral band (Fig. 1).

Regarding the wavelengths in concern, one can easily notify the huge discrepancy between water absorption coefficient for 905 nm and 1550 nm, being two orders of magnitude higher for the latter. It indicates very vital aspect of water impact on NIR laser range finding systems – rangefinders operating at 1550 nm are much strongly affected by water presence in the environment that those working at shorter wavelengths (905 nm, 850 nm).

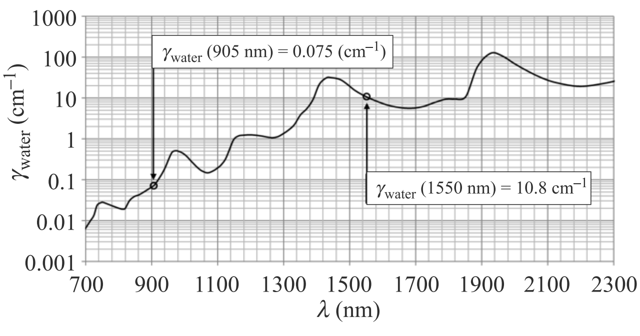

Fig. 1. Water extinction coefficient spectrum in NIR [9].

As mentioned previously, environmental water can interfere with rangefinder operation by its direct impact on atmospheric extinction coefficient γ and target reflectivity ρ which is put in under the quantitative consideration in the following part of the paper. Atmospheric extinction generally results both from scattering and absorption. Atmospheric water content manifests by humidity level, fogs and rains. The calculations of atmospheric extinction coefficient were performed in FASCODE (Fast Atmospheric Signature Code) environment. The results for typical mid-latitude conditions have been presented in Table 1. FASCODE is the recognized world-standard software for predicting atmospheric transmittance and radiance at high (line-by--line) spectral resolution. It performs accurate and speedy calculations from the ultraviolet through the visible, infrared & microwave spectrum (0 – 50000 cm^{-1}). The model accommodates standardized (WMO) atmospheric profiles, numerous aerosol models (including Fogs, Desert Dust and Maritime obscurations), water and ice cloud models (with precipitation). Spherical refractive geometry calculations are performed for any arbitrary line of sight chosen. Additionally, precise absorption modelling take advantage of spectroscopic parameters obtained from the implemented HITRAN database (the recognized standard compilation for atmospheric gases). In our research we modelled horizontal propagation of laser radiation at the altitude of sea level. High power pulsed semiconductor lasers typically feature significant line widths, so hi-resolution atmospheric transmission results obtained from FASCODE were convolved with hypothetical 10 nm width spectral line to obtain reasonable representation.

Table1.Atmospheric extinction coefficient calculated for 905 nm and 1550 nm wavelengths and typical atmospheric conditions.

Atmospheric extinction coefficient γ (km^{-1}), Rel. Humid. 50%					
Visibility (km)	1	5	10	15	23
λ = 905 nm	2.333	0.463	0.229	0.151	0.096
λ = 1550 nm	1.146	0.227	0.112	0.073	0.047

Approximately in typical conditions, atmosphere extinction coefficient for 905 nm is two times larger than for the wavelength of 1550 nm for all visibilities. It means that in general, optical radiation at 1550 nm propagates much better than at a 905 nm wavelength, however it does not provide any clue how this relation is affected by environmental water increased content. To obtain some quantitative data, similar calculations were carried out for increased humidity and oceanic aerosol (Table 2).

The results reveal a low impact of atmosphere humidity on extinction coefficients at both wavelengths. Only extreme relative humidity at the level of about 100% affects γ in non-negligible way, namely 13% *vs.* 19% in case of 905 nm and 1550 nm, respectively. Despite a substantial water absorption in NIR spectral band, humidity is not a crucial factor in range-finding performance degradation. It can be understood in terms of a very low volume water content in the air even in the cases of elevated humidity. Relative humidity is not the only merit number of environmental water presence in the atmosphere. Rains and fogs are phenomena related to a significantly higher water factor. They were analyzed extensively in FASCODE environment as well, showing essential discrepancy in extinction increase at both wavelengths in concern (Figs. 2 and 3).

Table 2. Atmospheric extinction coefficient calculated for 905 nm and 1550 nm wavelengths and selected atmospheric conditions.

Atmospheric extinction coefficient γ (km^{-1}), Rel. Humid. 70%					
Visibility (km)	1	5	10	15	23
λ = 905 nm	2.327	0.462	0.228	0.15	0.096
λ = 1550 nm	1.137	0.225	0.111	0.073	0.046
Atmospheric extinction coefficient γ (km^{-1}), Rel. Humid. 100%					
Visibility (km)	1	5	10	15	23
λ = 905 nm	2.615	0.519	0.256	0.168	0.108
λ = 1550 nm	1.363	0.270	0.133	0.087	0.056
Atmospheric extinction coefficient γ (km^{-1}), Oceanic aerosol					
Visibility (km)	1	5	10	15	23
λ = 905 nm	3.921	0.777	0.3833	0.252	0.161
λ = 1550 nm	3.577	0.708	0.349	0.229	0.145

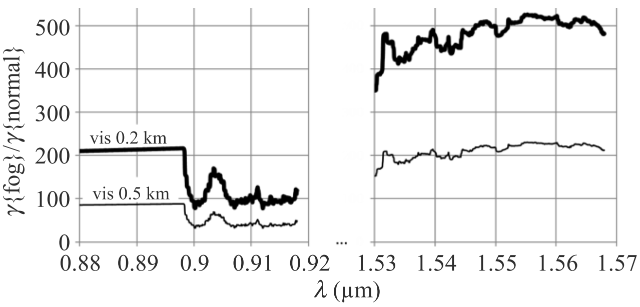

Fig. 2. Spectral ratios of extinction coefficients in the vicinity of 0.9 μm and 1.55 μm regarding fog conditions relative to normal visibility conditions.

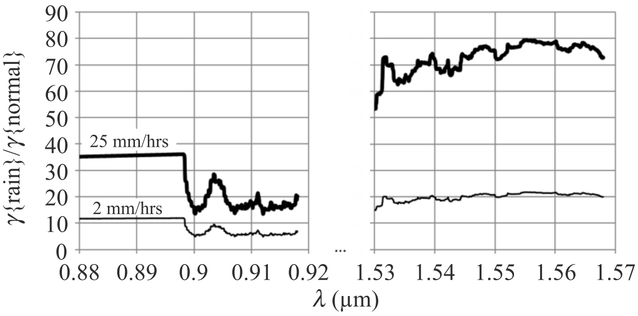

Fig. 3. Spectral ratios of extinction coefficients in the vicinity of 0.9 μm and 1.55 μm regarding rain conditions relative to normal visibility conditions.

In the case of dense fog with visibility of 200 m, atmospheric extinction coefficient increases dramatically, about 100 times at 0.9 μm band, however in 1.5 μm region it's much more – about 500 times. More transparent fog featuring visibility of 0.5 km, produces high optical attenuation as well – 60 times for 0.9 μm and about 200 times for 1.5 μm. It can be easily concluded, that fog decreases the range of rangefinders operating at both wavelengths, however those based on 1.5 μm optical radiation will suffer much more comparing to 0.9 μm modules. The quantitative analysis is provided later in the paper.

Unsurprisingly, the similar regularity can be noticed if rain is taken into account, however in a different scale. Reasonable rain rates were considered and 1.5 μm wavelength appears to be attenuated 2–4 times more than 0.9 μm. Obviously, more extreme rain falls would increase this discrepancy even further.

Although a water content of an intense rain is one order of magnitude higher than in the case of fog, it turns out that rain degrades laser propagation much less than fog. It can be explained in terms of significant scattering factor associated with fog droplets which size is comparable with wavelengths in concern. Raindrops are about 1000 times larger than fog scatterers, so geometrical optics well describes the transmission phenomena. Mie scattering of fogs appears to overcome an increased water volume absorption factor connected with rains. Similar tendency can be notified in the visible range of optical spectrum.

The second aspect of environmental impact in concern comes from target reflectivity which is affected either by water film covering wet surface or water presence in the space between the spores of porous surfaces. It's not the intent of the paper to develop theoretical models covering this issue, since experimental data were in the range of measurement capabilities. Extensive analysis of numerous (nearly two hundred) materials reflectance have been developed, putting focus on water impact (Fig. 4). Lambda 900 spectrometer from Perkin Elmer equipped with 150 mm PELA 1001 integrating sphere was used to evaluate the spectral characteristics. To validate the results, calibrated Spectralon Reflectance Standards were additionally applied. The main conclusion about wetness factor in reflectance is associated with strong water absorption originating in the vicinity of 1450 nm and still affecting the 1.5 μm wavelength. It can easily be noted in Fig. 4, where all "wet curves" correspond to dashed lines. Considering dry surface reflectance, most materials tend to feature increased levels at 1.5 μm, comparing to 0.9 μm (solid lines in Fig. 4). Due to surface wetness however, the reflectance drops much more dramatically for the former wavelength, again creating a larger vulnerability of 1.5 μm to the factor discussed. Statistically, one can assume than reflectivity of wetted terrain objects is reduced about 5–15% at 0.9 μm and about 10–60% at 1.5 μm.

The presented analysis shows that water presence in the environment has an impact on key parameters associated with a range-finder maximum achievable range. The scope of these effects is in full agreement with conclusions based on water absorption spectrum, however, their absolute magnitude is not a straightforward consequence. Atmospheric extinction is a result of absorption and scattering. Increased water content gives contribution to both effects, however, absorption is proportional to mean water density in the air, while scattering depends on size distribution of droplets. Optical radiation at 1.5 μm wavelength is attenuated much more than 0.9 μm due to absorption, however in case of scattering this order may be reversed. Dense fogs additionally feature the effects of multiple scattering and finally one can notice that huge discrepancy in a water absorption coef-

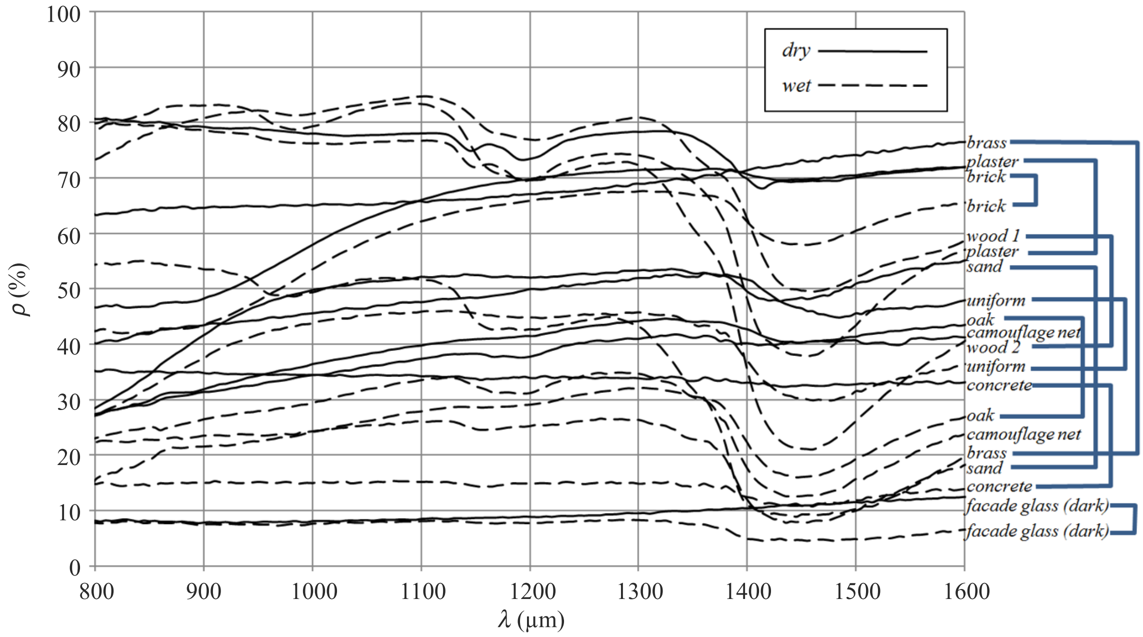

Fig. 4. Measured reflectance spectra of selected materials.

ficient is balanced to some extent by low overall water volume content and scattering effects.

Surface reflectivity wetness-dependence also corresponds to water absorption spectrum, however depending on the considered material the impact vary significantly. Water allocation on surfaces and its influence on reflectance should be regarded as a complex issue. A number of coexisting factors have to be taken into account. First of all water may create a film which provide volume absorption, however, also significant change of BRDF (Bidirectional Reflectance Distribution Function) may be introduced towards specular reflecting surface type. On the other side, dealing with range-finding equations, surface reflectivity ρ represents lambertian surface, which scatters light into a full hemisphere. Water may also penetrate external layer of some materials providing joint effects of multiple scattering and absorption. Magnitude of these effects strongly depends on the amount of water adsorbed and porosity of the surface. Modelling of such phenomena is a great challenge and in a number of cases proves to be inefficient. Calibrated measurements of a variety of specimen connected with database creation, although time-consuming, seemed to be more useful approach.

3. Range degradation scenarios analysis

According to the main purpose of the paper, the multi-scenario analysis has been performed to evaluate quantitatively the range degradation of 0.9 μm and 1.5 μm hypothetical modules, which in normal conditions have the same maximum range performance. The results of the previous paragraph were taken into account to calculate the direct range degradation factor $K_{1\to 2}$ [Eq. (6)] via numerical processing of modified Eq. (5)

$$K_{1\to 2}^2 = \frac{\rho_2}{\rho_1} e^{2\gamma_1 R_1} e^{-2\gamma_2 K_{1\to 2} R_1}. \tag{7}$$

We applied the damped least-squares (DLS) method also known as Levenberg–Marquardt algorithm (LMA) which is frequently used to solve non-linear least squares problems. For discrete set of ranges $R_1^{(i)}$, $K_{1\to 2}$ value was established by minimization of error Δ defined according to the following equation:

$$\Delta = \left[K_{1\to 2} - \sqrt{\frac{\rho_2}{\rho_1} e^{2\gamma_1 R_1^{(i)}} e^{-2\gamma_2 K_{1\to 2} \cdot R_1^{(i)}}} \right]^2. \tag{8}$$

It allowed to create discrete representation of the function $K_{1\to 2}(R_1)$ which was applied to calculate the maximum range in deteriorated conditions R_2 vs. normal conditions R_1:

$$R_2(R_1) = K_{1\to 2}(R_1) \cdot R_1. \tag{9}$$

The degradation factor was evaluated relatively to excellent visibility conditions (23 km) and target reflectivity of 10%, typically exploited by manufacturers when quoting maximum range of their range-finding products. Scenarios of environmental impact were configured to include the effects of reduced visibility and/or target reflectivity which normally happens during/after rain or fog occurrence. Results have been organized into plots where x-axis corresponds to original maximum range and y-axis is associated with the reduced maximum range (due to the specified environmental factor).

The rain impact has been presented in Figs. 5 and 6, referring to a couple of its intensities – light shower and intense rainfall respectively. In both cases, maximum range seems to be degraded significantly. Additionally, the combined effects of rain and wet surface have been attached, however, just a minor change can be notified.

In our research we examined multitude of different materials which can exist in natural environment and may become a target for laser range-finder. Statistically, the factor related to reflectivity coefficient reduction due to surface wetness appeared to be approximately 10% for 0.9 μm and 30% for a 1.5 μm wavelength which was taken into account in the following analysis. Reference (dry surface) level for reflectance was assumed 0.1 which results from current standards of range-finder testing procedures.

As expected, the results reveal significant discrepancy between performance degradation of hypothetical rangefinder operating at 0.9 μm *vs.* 1.5 μm. In extreme point of the analysis – during heavy rain, a 1.5 μm module may demonstrate as little as a half of a 0.9 μm maximum range (both have the same performance level in reference, good visibility conditions). The smaller the rain rate, the lower the discrepancy level is observed due to obvious water-content reason.

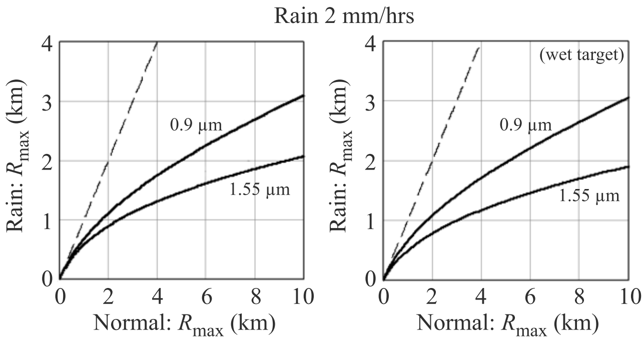

Fig. 5. Range degradation curves for 2 mm/hrs rain conditions.

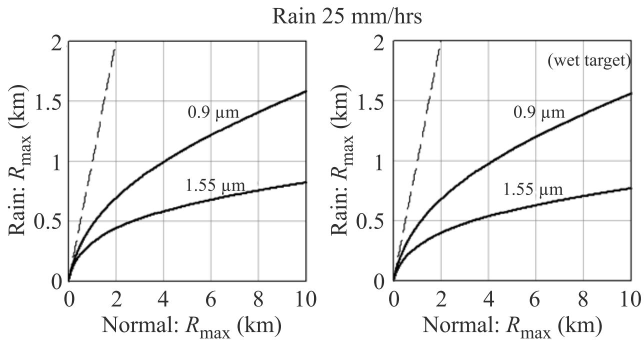

Fig. 6. Range degradation curves for 25 mm/hrs rain conditions.

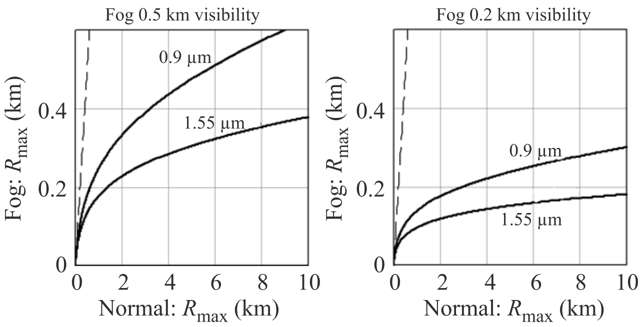

Fig. 7. Range degradation curves for fog conditions.

Fog impact analysis was also developed for two representative cases – mild and dense fog with visibilities of 200 m and 500 m, respectively (Fig. 7). Performance of both rangefinders turns out to be degraded much more drastically than in the case of rains. Even lighter fog creates larger performance reduction than heavy rain, which is in full agreement with the issues discussed in the previous paragraph. Again, a 1.5 μm range-finding suffers much more than 0.9 μm counterpart, reaching about 60% difference in measurable range in adverse conditions.

Concerning target surface reflectivity which can be reduced due to its wetness, the effect appeared to be much less crucial than the impact of atmospheric extinction coefficient increase. The results of the analysis which included just ρ modifications with atmospheric extinction remaining unchanged are presented in Fig. 8. Such situation may occur directly after rain, when visibility returns to be excellent, however objects are still wet.

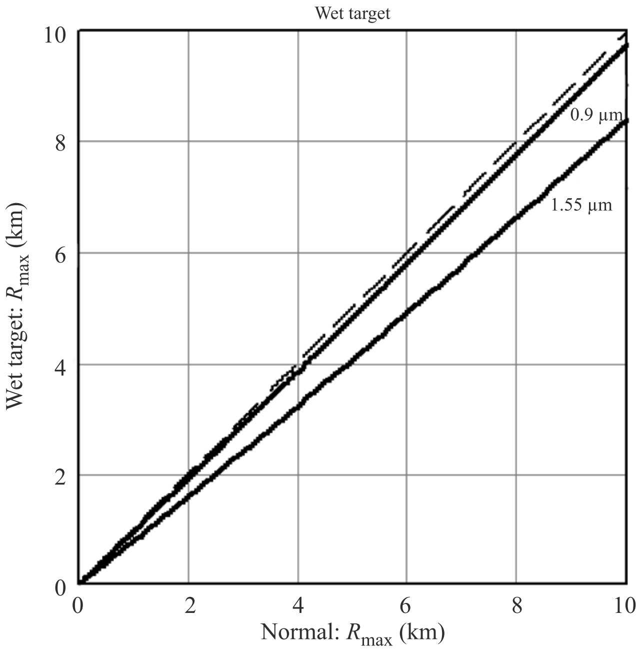

Fig. 8. Range degradation curves due to exclusive impact of target surface wetness [(10% (0.9 μm) *vs*. 30% (1.5 μm) reflectivity drop)].

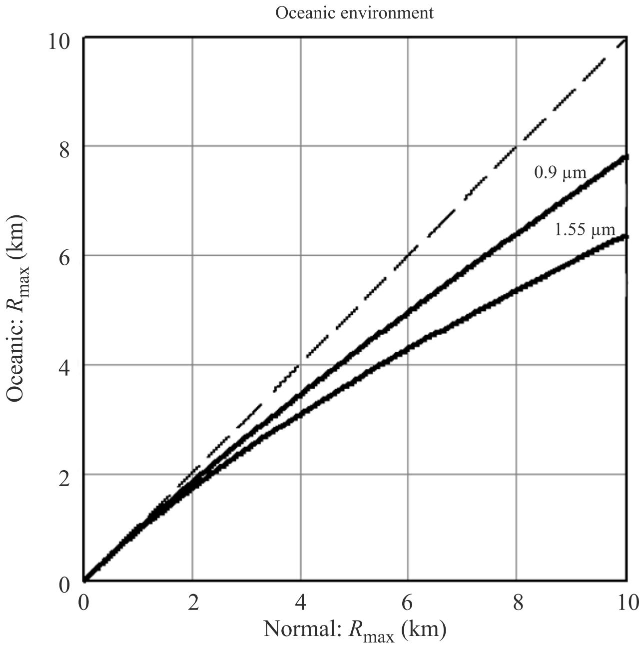

Fig. 9. Range degradation curves due to oceanic aerosols attenuation.

The evaluation was developed for mean values of all surfaces analyzed, giving the final performance difference at the level of about 10–15% and 0.9 μm still leading a 1.5 μm hypothetical module.

Additional calculations included oceanic environment where an increased amount of water droplets and salt is observed. The obtained characteristics are presented in Fig. 9, keeping the 0.9 μm *vs*. a 1.5 μm performance degradation discrepancy at the level of 10–15%, favouring the former wavelength.

4. Conclusions

The impact analysis of adverse factors related to environmental water on laser range-finding has been performed. Two wavelengths of special concern were inspected and compared in detail – 0.9 μm and 1.5 μm. Due to much higher (two orders of magnitude) water absorption at the latter wavelength, larger susceptibility to elevated humidity, rain, fog, wet target was expected in this case. To obtain quantitative results associated with range degradation, a range-finder equation was transformed to extract the influence of atmosphere transmission and target reflectivity. Extensive analysis of atmospheric extinction variations in a variety of conditions have been modelled in FASCODE environment. Additionally, a numerous reflectance characteristics have been measured and collected to assess the real impact of surface wetness on reflectivity coefficient spectrum. The final results were obtained via numerical processing and organized into intuitive plots enabling to estimate the hypothetical rangefinder performance degradation by comparing maximum range before and after the change in environmental conditions.

Environmental water impact on atmospheric extinction and surface reflectivity is a very complex issue. Additionally, one should assume extremely large variety of configurations in terms of *weather status – measured object*. Concerning water-content dependence of atmospheric extinction, a whole spectrum of thermo-dynamical conditions may occur due to local climate, terrain elevation and random factors. There is a number of specific atmospheric aerosol types (rural, urban, oceanic, tropical and others) that potentially could behave differently when faced to increased ambient water content. Apart from that, atmospheric water can lead to condensation of various chemicals that selectively absorb electromagnetic radiation. Regarding surface reflectivity of terrain objects and its changes due to wetness, it is even a more complex problem. Surface structures of different materials may be totally different in terms of dry-reflectivity, porosity, ability to attract water, etc. Film of water located on some surfaces may change the reflection type from lambertian to nearly specular. In other cases water may permeate into the object structure and change reflectivity coefficient without losing hemi-sphere-scattering geometry. Additionally, water volume absorption provides its relevant factor. The obtained reflectance characteristics confirm the multitude of effects. Generally, if dry, most objects reflect radiation at 1.5 μm slightly better comparing to 0.9 μm, however, one can spot some exceptions to this rule (for example military uniform). Wetted surfaces appeared to "darken" at both wavelengths, but this effect was much stronger concerning the spectral vicinity of a 1.5 μm wavelength. Unsurprisingly, universal rigorous model which would be representative for all possible surface types does not exist. It was the reason to adopt statistical point of view based on real-life measurements of numerous authentic materials reflectivity. Finally, the detailed multi-threaded analysis enabled to evaluate some environmental representatives associated with specific water-related effects (fog, rain, humidity). Implementing them in range-finder equations allowed to estimate the range degradation factors for both wavelengths in concern.

The results show clearly that, exposed to unfavourable weather conditions, a 0.9 μm range-finding module will keep its nominal parameters much better than a 1.5 μm equivalent. The most dramatic discrepancy occurs in rainy atmosphere, where the former may reach two times larger distances than the latter in case of 25 mm/hrs rain rate. Fog appeared to be the most suppressing factor for both wavelengths, reducing rangefinders performance to several hundred meters. Still, the 0.9 μm module seems to measure up to 60% longer distances than the same good-visibility-performance 1.5 μm counterpart. Target wetness level turned out not to be the major range determining factor when compared to atmospheric extinction impact, again favouring the 0.9 μm suspected range level about 10–15% higher than in case of a 1.5 μm wavelength. Oceanic environment was inspected as well producing about the same discrepancy. Humidity effects didn't demonstrate any noticeable effects on rangefinders operation at both wavelengths. It should be underlined that especially if long (several kilometers and more) distances are taken into account, it is atmospheric extinction which becomes the performance main determining factor. Two-way atmospheric transmission in adverse conditions may drop a few orders of magnitude – to the levels significantly below 0.1%, which comparing to typical objects' reflectivity is a major reduction.

The discussed vulnerability to unfavourable weather conditions is not the only factor determining which wavelength is better in general in the field of range-finding. There is a lot of other points that should be examined, for example eye-safety issue. 1.5 μm is much more safe wavelength than 0.9 μm which in some applications may be the most crucial issue. This fact allows to use more powerful lasers without violation of eye-safety regulations, which in consequence has a positive impact on maximum achievable range. Some military aspects of range-finders classification come from potential enemy observation capabilities [10] – 0.9 μm radiation is visible by most even obsolete night-vision systems (in case of 1.5 μm it is not so) and that's why some users may prefer 1.5 μm, simply because they do not want to reveal their positions during measurements. There are also other factors like dimensions, components price, overall efficiency, spectral detectivity, etc. which are beyond the scope of this paper.

Concluding the obtained results, it's worth to underline their essential significance. Maximum range of a rangefinder is one of its most important parameters, sometimes crucial when determining its usefulness in certain applications. Rangefinders manufacturers, aiming to increase attractiveness of a product, provide its maximum range valid for excellent visibility conditions. Doubtlessly, real-life applications are not limited to such optimistic scenarios. It appeared that having side by side, two rangefinders performing identically in good weather conditions (the same quoted maximum range), one operating at 0.9 μm and the second one at 1.5 μm, they will feature significantly different efficiency in adverse weather conditions. 0.9 μm wavelength rangefinder seems to be much more weather-proof solution and, thus recommended for applications were all types of environmental conditions have to be taken into account.

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