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Research Article

A Short Technical Note on the IR Signatures Studies and Designing Aspects of the IR Technology Devices for Defence Aircraft

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ABSTRACT

The purpose of the present communication is to give a short technical Analysis of the impotant IR Signatures Studies, and the Designing Aspects of the IR Technology Devices for Defence aircraft for optimizing their performance. The Designing Aspects have been discussed on the basis of Lock-in-envelope and Radiant Flux Attenuation by Transmission through Atmosphere, by considering equations and computations for Lock-on Envelope. The paper is expected to be very useful for the Researchers and Technologists engaged in the designing and fabricating the IR based devices for modern fighter aeroplanes, and the Techniques for protecting them from detection and enemy attack.

Keywords: IR signatures studies; Lock-on-envelope of IR emissions from defence aeroplanes; Designing aspects; Battlefield aircraft; Helicopters

INTRODUCTION

Infrared signature means the appearance of object to Infrared sensors, the term being mainly used by defense scientists and the military, which is a function of many factors, including the shape and size of the object, temperature, and emissivity, and reflection of external sources-like earthshine, sunshine, and sky shine from the object's surface, the background against which it is viewed, and the waveband of the detecting sensor. It is to be noted that the infrared signature of a target like fighter aircraft and battlefield helicopter viewed against a field varies significantly with many parameters like changing weather, time of day, and engine loading. Thus, it cannot be assigned a unique value or unique definition. Mostly, the IR Signature of an object is considered as the apparent temperature difference at the sensor, or the contrast radiant intensity (CRI) definitions.

IR signatures based devices for military aeroplanes and helicopter's

IR Signatures based devices for military aeroplanes and helicopters are being undertaken in Important Defence Establishments: The subject of IR Signatures has recently been the subject of Research [1-14]. Though the subject has strongly been investigated from early days, in the European countries and the USA; a lot of interest has recently been shown by various Defence Research and Development Establishments of countries like India and Canada. Some aspects of IR Signatures for the Devices e.g., land and marine vehicles have drawn the attention of the Researchers and Aeronautic engineers. Some such work is going on in some establishments including Gas Turbine Research Establishment (GTRE), Bangalore, Defence Laboratory, Jodhpur Instruments Research and Development Establishment (IRDE), Dehradun, Naval Science and Technological Laboratory, Visakhapatnam, and Defence Science and Technology Organisation-Defence Research and Development, Canada. The work on various IR Signature devices like exhaust emission thermal IR signatures of military aircraft, and Imaging Infrared (IR) seeker for top direct attack capability for the defence aeroplanes is being carried out by considering the lock-on-envelope equations and computing them by computer software, which are not easily commercially available.

Difficulties faced by the battlefield helicopters

The battlefield helicopters are inherently unstable and difficult to fly. This is because of the fact that they have to fly at low height, the whole of the day and night. The other difficulties faced by them are: (i) Zero speed at hovering, (ii) Constraint of Weight, (iii) Constant of real estate, (iv) Vibration and fuselage flexure, (v) High noise level, (vi) Vulnerable rotors, (vii) risk of rotor-induced signal modulation, (viii) Visual signatures, and (ix) Strong IR signature,

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which makes it very vulnerable for being detected and liable to be targeted by enemy. In addition, there are some Asymmetric conflicts like: (i) Conducted increasingly in urban environments, thus being more risky, (ii) Littoral operations becoming more frequent, (iii) Entire operational area is mostly a combat zone, (iv) Many insurgents disguised as civilians, armed with armed mainly with adhoc and portable weapons, and also not using aircraft, (v) Assassinations conducted by all parties, and (vi) Popular support crucial to all parties.

Research efforts needed

Researchers must understand the operational environment, in which the important parameters are: Enemy and population, culture, hearts and minds, Climate, topography, atmospheric conditions, Friend-foe-neutral signatures, along with IR/UV background. Requirement of adhering to strict ROEs, Ejection of MVT flares, need for low-hazard flares, Laser safety, UN Protocol on Blinding Laser Weapons, Need for NLW laser, Need for uniform horizontal capability, Enemy detection, identification location, and suppressive fire, Threat detection, identification, location, and CM execution, and strict requirement for Must minimize obscured sectors.

Challenges for photonics to overcome some problems in IR signatures studies

To overcome some of the problems in IR Signature Studies, especially related to helicopters are: (i) To ensure Short engagement ranges and timelines, (ii) To develop Short (2-4 s) IR Manpads, and LBR antitank missiles,(iii) To design and fabricate very short (<1 s): Ballistic weapons e.g., Those from Starstreak like Super short (milliseconds): IEDS, anti-helicopter mines.

Photonics Researchers have many Requirements, and face many challenges including(i) Standoff detection of CBRE threats, (ii) Chemical e.g. FTIR, which is sensitive to IR background clutter, and differential LIDAR, (iii) Biological e.g., fungi spores, pollen, common bacteria, (iv) Radiological and Nuclear): More or less same as (v) Explosives, which needs more concerted efforts, (vi) High spatial resolution, and ISR compatibility, (vii) Accurate and positive identification and target elimination, (viii) Cueing by other ISR assets à Compatibility and data fusion, (ix)Priorities for shared resources, which pop-up frames on MFD; and have to be determined in advance, and (x) on-board sensors other than acoustic sensors, since Helicopter are too noisy for acoustic sensors.

In fact, integrated photonics architecture is required. It is to be noted that DIRCM is mostly not in use for combat flight. The strong requirement is for the development of (i) Multipurpose laser, and (ii) Common apertures and Receivers. However, there are some practical limitations e.g., No combined MLD-LWR; no combined damaging-jamming DIRCM laser. Thus, the idea of improved integration is quite difficult, and requires concerted combined efforts by various Photonics groups in the leading Research Establishments worth keeping in mind.

Adaptive camouflage for defence aircraft

Recently, the survivability of an aircraft has been found to be increasingly difficult; due to various factors including, the increase in the usage of Infrared (IR) guided Anti-Aircraft Missiles, because of the availability of Man Portable Air Defence System (MANPADS) with many terrorist organizations. Hence, aircraft IR signatures are becoming more important than any other signatures. The exhaust plume ejected from the aircraft is an important source of IR signature in military aircraft, which use low bypass turbofan engines for propulsion.

In modern warfare, the Infrared guided missiles are a source of energy threat for modern naval forces. In fact, the vulnerability of ships can be significantly reduced by application of countermeasures including infrared decoys, and IR signature reduction. A simulation toolset is commercially available, which can be used for assessing the effectiveness of these measures. Interestingly, the toolset consists of a chain of models, which calculate the infrared signature of a ship (EOSM) and decoys, and also generate infrared image sequences of the ship in realistic environment of sea and sky background (EOSTAR). Another useful model- Complete missile fly-out model (EWM) uses these images in closed loop simulations, and for the computation of countermeasure effectiveness against simulated seekers.

Adaptive Camouflage Techniques for a Light Armored Vehicle is an important topic being looked into by the Scientists and Technologists engaged in IR Signatures Studies. It is well known that Camouflage has been an important survivability technique for battlefield platforms, installations and personnel, and so has been a subject of recent attention of many Scientists [15-21].

It has now been well understood that IR radiation is the most vital stealth signature, which has to be minimized to conceal the naval ships from the IR-guided missiles. The intensity of the ship signature depends on the amount of plume and metal surface temperatures, ambient conditions, and ship hull and structure temperatures. The plume can be minimized by designing and developing an infrared Suppression System (IRSS) for diesel engines by various techniques, including the use of the educator diffuser principle with film cooling rings, where the educator acts to provide suction effect by controlling the vacuum at higher velocities.

Though the Modern sensors are able to resolve very small differences between targets and background, yet a traditional static camouflage solution maintains a close enough match to its environment only if the environment also remains static. Hence, to maintain low detectability in a changing environment, camouflage systems must be able to adapt. Wheaton et al. [13] have demonstrated the concepts of adaptive camouflage for a light armored vehicle (a CABSTRAC Canadian Coyote) in a desert environment.

Aircraft designing aspects based on lock-on-envelope and radiant flux attenuation by transmission through atmosphere

Calculations for lock-on envelope: It is important to note that the lock-on envelope of target aircraft is to be calculated for determining its susceptibility against a heat-seeking missile and depends on the aircraft's infrared (IR) signature level (IRSL). Generally, the lock-on envelope is estimated in 3-5 mu m and 8-12 mu m bands, considering internal and external sources of IR signature from surfaces of aircraft engine layout. This is calculated by (i) analytical estimation of solid angles subtended by aircraft surfaces, (ii) prediction of aircraft surface temperatures from convective and irradiative heat transfer model, (iii) computation of atmospheric transmission and background radiance, and (iv) estimation of earthshine, sky shine, and sunshine irradiances.

Finally, polar plots in 2-D for lock-on range, for vertical and horizontal planes are analyzed, to study the role of internal and external sources for different aspects. This is a complicated job, which is done by commercially available software, based on the following approach:

The RMS signal voltage is just the integration of the products of spectral radiant power incident at the aperture of the optics and the responsively; which on simplification becomes equal to some term dependent on selectivity, rms noise voltage, area of the detector, noise equivalent bandwidth, and average outgoing quality as given by the RHS of the following expression:

The lock-on envelope has to be obtained in the analysis and the related studies of the IR Signatures. The most useful tool is the finding of the Lock-on Envelope. The calculations for Lock-on Envelope are done by the following equations:

$$V_s = \int \Phi e(\lambda) R_v d\lambda = \left[D^* V_n \Big/ \left(A_d \Delta f \right)^{\frac{1}{2}} \right] AOQ \quad (1)$$

$$\Rightarrow \frac{V_s}{V_n} = SNR = \frac{\left[\dfrac{q}{IFOV} \right]}{\left[\dfrac{NEP}{AOIFOV} \right]} \quad (2),$$

and

$$SNR = \frac{Q\left(D^*\right)\left[\pi \left(D_0\right)^2 IFOV\right]}{\left[4\left(A_d \Delta f\right)^{\frac{1}{2}}\right]} \quad (3)$$

Here the various parameters are as:

$\Phi e(\lambda)$-Spectral radiant power incident at the aperture of the optics,

R_v Responsivity,

IFOV-Average outgoing quality-instant field of view

AOIFOV--Average outgoing instant field of view

Δf -Noise equivalent bandwidth in Hz,

V_n -RMS noise voltage,

D^* -Detectivity,

A_d-Area of the detector,

D_O-Aperture diameter,

q-The target skin aerodynamic heating IR radiant intensity of interest,

AOQ- Average Outgoing Quality which is the expected average outgoing quality level (The AOQ plot represents the relationship between the input quality and the outgoing quality), and, NEP- Noise-equivalent power., which is a measure of the sensitivity of a photo detector or detector system, defined as the signal power that gives a signal-to-noise ratio of one in a one hertz output bandwidth.

Another approach and formula for evaluating the attenuation of the signal on transmission through the atmosphere, as a result of scattering by particles of different size in haze and fog, is discussed here.

The radiant flux is attenuated on transmission through the atmosphere. The transmission of the signal can be (d4) expressed as:

$$T=\exp\{-(a + s)r\} \quad (4),$$

where

T is transmittance a, is absorption coefficient, s is scattering coefficient, and r is distance of travel of the signal.

It is important to note that though absorption can be important in some bands; scattering is mostly the dominant effect if the traditional infrared transmission windows are employed.

The scattering coefficient is the summation of the two types of scatter; small particle or Rayleigh scattering, and large particle or Mie scattering. Rayleigh scattering is a function of the fourth power of the inverse of the wavelength, and is negligible below 1um. However, Mie scattering has little dependence on wavelength, and for photon wavelength small compared to the particle size, the scattered is indiscriminate. In case of periods of haze, the particulate or marine aerosol has dimensions of less than 0.5 μm, and so the dominant process is Rayleigh scattering. Hence, the infrared signal undergoes low transmission losses in comparison to the zero visible signals.

For the case of the periods of fog with a peak size distribution of the marine aerosol between 5 μm and 15 μm, Mie scattering is dominant. Clearly, the Scattering losses affect the visible and infrared signals accordingly. Thus, the propagation of the infrared signal has a distinctive physical characteristic, which contributes to the enhancement during periods of low visibility.

Thus, it is clear that the designer has to take into consideration the scattering and absorption while designing the system, which implies that ho, has to study the environment likely to be encountered at the site. In addition, the designer has to study the IR Signature before fabricating an actual object.

The computation is quite difficult, and so in the design phase, it is desirable to use a computer for predicting the infrared signature before actually fabricating the real object. In fact, to optimize the results, many iterations of the prediction process can be performed very fast, as compared to the use of a measurement range, which is time-consuming, and also error-prone.

Because of the great utility of the IR Signatures, many software companies have built infrared signature prediction software packages, which require the particular CAD model, in addition to the parameters for describing a specific thermal environment, along with the internal temperatures of the platform and thermal properties of the materials of construction. Interestingly, the software solves a number of thermal equations at the boundaries, and for the electromagnetic propagation in the particular IR waveband. It has to be noted that the primary output is a measure of infrared signature, surface temperatures, and also visual representations of the likely appearance of the scene to various IR detectors.

Infrared signature prediction models are very difficult to validate except for simple cases, because of the difficulty in modeling a complex environment. The sensitivity analysis of this software and experimental measurements has shown that small variations in weather can have a significant effect on the results.

Clearly, there are limitations on achieving the correct values from modeling the infrared problem, and sometimes experiments have to be performed for achieving accurate idea about the nature of the shape and physical appearance of the object in the IR wavebands.

The designers have to minimize IR signature, but we have to be stealthy, before an enemy is able to launch an IR missile at us. It is clear that an infrared missile needs to know from the launcher the direction of sight, which implies that by our stealth technique, we are able to minimize the amount of time the enemy knows about our existence. By being invisible on radar, so that they are not able to see us approaching them until they spot us visually, at which point they are either targeted or have just few seconds for reacting.

Protection zone monitoring based on radar technology for defence aircraft and missile systems

Many Technologies are available for Protection Zone Monitoring based on Radar Technology and Missile Systems. These are briefly discussed below:

(i) **A Missile Approach Warning (MAW) system:** MAW is an important part of the avionics package on many military aircraft, in which a sensor detects attacking missiles, and its automatic warning helps the pilot to make a defensive maneuver, and then deploy the available countermeasures for effectively disrupting the missile tracking.

(ii) **Guided surface-to-air missile (SAM) systems:** SAM systems are very important, and were developed during World War II, and in response to this, the electronic countermeasures (ECMs) and flying tactics were developed to overcome them. These systems have been found to be quite effective only if a reliable and timely threat warning is given.

(iii) **Protection zone monitoring based on radar technology:** It has been observed that with the advent of the world's first safe complete solution for protection zone monitoring based on radar technology, the application of Pilz has been increasing rapidly in the field of safe sensor technology. One such useful system in this category consists of the safe radar system LBK System from Inspect S.P.A., and the configurable small controller PNOZ multi 2. This complete solution has been found to be unique in the sense that it enables complex applications and rugged environments to be monitored safely, even in the open fields, since the robust radar technology ensures high availability even in the presence of external influences including dust, dirt, smoke, rain, light, and shocks.

(iv) **Safe protection zone monitoring with radar technology:** Based on the radar technology frequency modulated continuous wave (FMCW), the LBK System enables us to do volume monitoring with a frequency of 24 - 24.25 GHz, and hence can be used up to SIL 2, PL d and Category 2. The advantage is that there are many safety-related functions offered by this system, including the detection function and the restart interlock. The function of the detection function is to bring the machine to a safe state, and the restart interlock prevents the machine starting up automatically, when there are some persons still in the danger zone.

(v) **Flexible setup of protection zones:** The safe radar system solution is very complex, and depending on the application, it has, up to six radar sensors, one control unit, and the configurable safe controller PNOZ multi 2. In addition, depending on the size of the area to be monitored, a wide or narrow protection zone has to be set up for each sensor. The wide protection zone has an opening angle of 110° horizontally and 30° vertically, and the narrow protection zone has an opening angle of 50° horizontally, and 15° vertically. The designer of the system has to consider all these points for the optimum performance of the system.

(vi) **Simple configuration with the LBK system configurator:** Another geometrical aspect to be considered by the designer is that the actual protection zone of the sensor depends on the positioning, installation height and inclination (horizontal and vertical) of the sensor. Obviously, in this way, flexible shapes can be created for the protected areas.

The designing aspects in the (v) and (vi) cases need the experience and expertise of the designer, who has even to take the help of the computer software to get the optimum results.

DISCUSSION

IR Signatures are becoming increasingly important for not only military applications like Battlefield aircraft, helicopters, Warships, Protection Zone Monitoring based on Radar Technology and Missile Systems, and safe radar system solution; but also in scientific, medical, and industrial fields. Commercial CFD software are available for some important cases like predicting the plume thermo-physical properties and thus evaluating the IR radiation emitted by the plume. One such study has been done by Rao [11], who has done a very detailed study of the Infrared Signature Modeling and Analysis of Aircraft Plume. It can now be understood that the ability to perform an IR analysis of a platform requires so many parameters including:(i) an understanding of IR phenomenology, (ii) thermal properties of the materials likely to be used, (iii) heat transfer equations, and (iv) an expertise of using a commercially available software like Ship IR software. It has been observed that the defence departments of many countries have specialized laboratories working on IR analysis. Interestingly, Davis interacts with these laboratories in international Conferences for enhancing the Ship IR software and introducing improved analysis methodologies. As we know that the IR detestability of our platform varies with environmental and operational conditions. This problem has been solved by analyzing a large set of weather data in the region of operation, and then choosing a few of environmental conditions with the same statistical characteristics as the weather data. So, the software is highly likely to provide a fairly accurate result. However, this process requires the skill and expertise of the designer. Davis and Thompson [20] have developed an IR Signature specification technique for military platforms using modern simulation techniques; and thus have given an approach for the designing IR Devices for the dete and protection of military aeroplanes and helicopters. However, there are many Challenges for Photonics to overcome some problems in IR Signatures

Studies. Thus, a lot of concerted efforts are needed to be made in this evolving field. Comfort, and health, yet most buildings have a much higher rate of air leakage than the required one. This is because of the poor design and construction, which results in an optimized performance. Yang et al. [21] have discussed the Infrared signature measurement of targets accounting for atmospheric attenuation.

CONCLUSION

The designing aspects have been discussed on the basis of Lock-in-envelope and radiant flux attenuation by transmission through atmosphere, by considering equations and computations for Lock-on Envelope. The paper is expected to be very useful for the Researchers and Technologists engaged in the designing and fabricating the IR based devices for modern fighter aeroplanes, and the Techniques for protecting them from detection and enemy attack. Thus, it can be concluded that the subject is on a firm footing, and evolving fast.

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