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Infrared Background and Missiles Signature Survey

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ABSTRACT

The proliferation of the missile threats in the existing threat scenario for airborne platform is a serious point of consideration for any mission planning. Missile warning system is an electronic warfare support system which gives warning to the pilot when a missile is detected in the scenario. The airborne platform has to be installed with missile warning sensors to give a spherical coverage, so that the sensors can detect the IR intensity variation in the ground scenario. This IR intensity variation has to be further analysed to differentiate the raising missile intensity from the varying background clutter. In order to differentiate the threat from the background clutter, the system should have sufficient background data set for online comparison thereby having less false alarm rate. The efficiency and performance of any missile warning system is validated with respect to its probability of declaration against the false alarm rate. Hence, to realize an efficient functioning of missile warning system, building IR background data base and missile signature database are the primary task. This paper details the methodology to be adapted for the building of tactical missile IR signatures and background data.

Keywords: Infrared signature, missile warner, missile plume signature

1. INTRODUCTION

The widespread availability of man portable air defence system (MANPADS) has made the airborne platform more vulnerable to missile threats[1]. The fighter aircraft which has more maneuvering capability during mission even at high altitude is becoming easy target for air to air missiles also. To detecting and tracking the missile during the maneuvering mode of the fighter platform at high altitude is a challenging task. Also at higher altitude, only IR based sensors can detect these missiles being fired upon the target aircraft. For such sensors, performing with same characteristic at lower altitude as at higher altitude is a real challenge. To differentiate the threat against the background, the database built in the system should be highly efficient and dense. This paper brings out the methodology to be adapted for building such database.

2. SENSOR TYPE DESCRIPTION

All substances absorb and radiate IR energy, provided they are not at a temperature of absolute zero (0 °K). The hot objects emit more energy and the peak wavelength of emission decreases as T^{-1}. IR energy has the same features as visible light in terms of traveling in a straight line at $3x10^8$ m/s and being reflected or absorbed when hitting the surface of an object. In view of this an IR based missile warning system is bound to have lots of detected objects which need to be analysed before setting any alarm to the pilot. The screening of the image at any one instant of time in two spectral bands (3 μ – 4 μ and 4 μ – 5 μ) prove to be a good feature for achieving reduced false alarms. Both the bands are simply designated as red band and blue band. The red band lies in the red spike region of the band of CO_2. This provides maximum sensitivity for detection of a hot hydrocarbon combustion source. The blue band lies in the atmospheric window just above the red band. For a combustion source such as a burning missile, the intensity in blue band is significantly lower than the red spike band. For a hot black body source such as sun glint, bush fire etc, the reverse intensity relation is true. The band widths were selected to provide equal photon flux in the two bands at 300 K. This helps to balance the dynamic range required to maintain sensor response in both the bands.

3. THREAT AND THE BACKGROUND

IR seeker technology enabled the missile-independent, point-defense system. Their small size makes it cheaper as well as possible to rapidly change locations and create a threat anywhere. Therefore, they do not require as complicated a system as in RF technology. Because of these reasons, MANPADS have proliferated widely. While a missile costs around 30 K $, it can shoot down a 30 million $ aircraft. Threat size, location, cost and effects combine to create an asymmetry between these missiles and aircraft. The following Fig. 1 shows the environment dealt by any IR missile warner system and complexities dealt by the system for identifying the emitter as the threat to the platform.

4. IR SIGNATURE

There are so many IR points of interest in the environment. Aircraft body itself is a big IR source for the Missile Warner System. Sunlight is reflected and some of it is absorbed and reemitted by the airframe (skin emission). The exhaust plume

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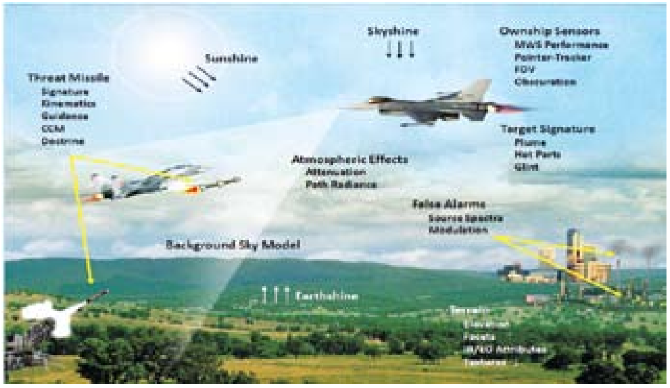

Figure 1. Environment seen by any missile warner.

expands, then becomes smaller and cools behind the aircraft; it also heats some parts of the airframe. Hot vents as well as landing and operating lights are also IR sources in motion. The plume of the engine become scooler further away from the engine, and it makes a larger wavelength as the temperature of the plume decreases.

$$\lambda = \frac{2898}{T(K)}\mu$$

The large IR signature produced by the engines enables missiles to detect, acquire, and track the target from longer distances. Typical plume emissions are 3 µm – 5 µm and skin emissions are 8 µm – 12 µm. However, to a large extent the IR intensity of the aircraft are available across many literatures. Typical values are given in the following Table 1.

Tabel 1. Recorded IR intensity of difference platforms

Aircraft Type	Intensity (Wt/Sr)	
	2 µ – 3 µ	4 µ – 5 µ
Rotary wing	10 – 100	100 – 300
Fixed wing (Propeller)	20 – 200	200 – 500
Jet fighter	50 – 1000	1000 – 10000
Transport	100 – 1000	100 - 5000

A typical flight consists of three parts: takeoff and climb, en route, and descent and landing. Different kinds of missiles threaten the different phases of flight. Vulnerabilities change according to the mission types and components. Unlike slow moving platforms (helicopter and transport), fighter aircraft is challenged by all types of threats. While takeoff and landing, MANPADS are the main threats and air to air missile is a big threat during combat as illustrated in Fig. 2.

Generally, military aircraft operate in a highly threatened environment. When the mission dictates, they operate at less than 15,000 ft for airborne delivery, search and rescue, and special operations. Those missions might be over hilly terrain, desert, or dense vegetation and in all weather conditions, such as sunny, snowy, or rainy. In order to detect a threat with good probability of declaration, system should be intelligent enough to identify the clutter. The database should be rich with data from all types of clutter which can pose as a threat to the system thereby resulting in false declaration.

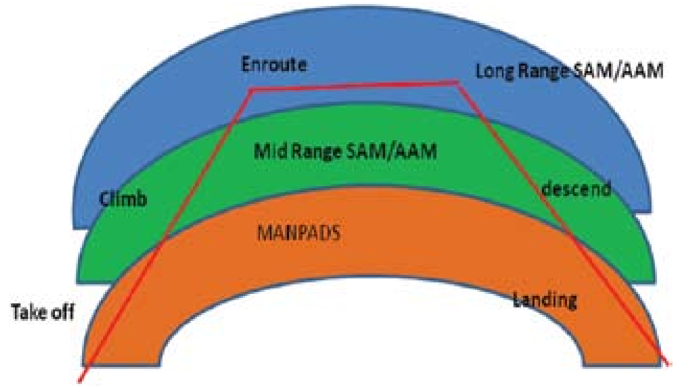

Figure 2.Threats at different phases.

5. MISSILE PLUME SIGNATURE

For recording the tactical missile plume signatures, along with sensor in study, a spectral radiometer needs to be used. The radiometer should be installed with the filters of interest (generally 3 µ - 4 µ and 4 µ– 5 µ). Missile Signature is the net effect of the thermal emissions, background absorption and sunlight reflection. In addition, the missile signature must be discriminated from any background upon which it is superimposed. The magnitude of a typical missile plume signature at a given wavelength depends on the size of the plume, density and temperature of the gases and particles in the plume and characteristic radiative properties of those gases and particles at that wavelength. These parameters are in turn affected by factors such as missile size, propellant composition, nozzle design, altitude and velocity.

5.1 Sources of Missile Signature Radiation

Table 2 gives the typical plume constituents and their infrared emission bands[2]. Water and carbon dioxide molecules are common to most propulsion system plumes. In many types of plumes, these molecules are abundant and are the major contributors to the infrared plume radiation. The water and carbon dioxide molecules are also present in the atmosphere surrounding the plume. In atmosphere, they serve as the primary absorbers of infrared radiation. Losses are significant only after a few feet of atmospheric transmission. The spectral and energy variation of a source as a function of time is a critically important descriptive factor. In solid rocket motors, the plume

Table 2. Principle plume exhaust gases IR emission bands

Molecule	Band centers (µm)
CO_2	1.96, 2.01, 2.06, 2.69, 2.77, 4.26, 4.68, 4.78, 4.82, 5.17, 15.0
CO	4.66, 2.34, 1.57
HC1	3.46, 1.76, 1.20
H_2O	0.94, 1.1, 1.38, 1.87, 2.66, 2.73, 3.2, 6.27
NO_2	4.50, 6.17, 15.4
N_2O	2.87, 3.90, 4.06, 4.54, 7.28, 8.57, 16.98
OH	1.00, 1.03, 1.08, 1.14, 1.21, 1.29, 1.38, 1.43, 1.50, 1.58, 1.67, 1.76, 1.87, 1.99, 3.87, 4.14, 4.47
SO_2	4.0, 4.34, 5.34, 7.35, 8.69

radiance varies rapidly and, in some cases, may be of very brief duration. With certain types of missiles, the boost and sustain motors may be made with different propellant; therefore, two or more radically different types of radiation sources may be encountered. It is important that a measurement system have an adequate response time to deal with the fluctuations of the source.

5.2 Missile Signature Collection Instrumentation

The temporal, spectral, and spatial features of tactical missile signature (TMS) radiation can be affected by factors such as propellant composition, nozzle effects, temporal effects, aspect angle, altitude, velocity, range, atmospheric conditions and trajectory[4]. All these aspects need to be considered while deriving the instrumentation for missile signature collection. The major areas to be considered are missile, position information, radiometric and atmospheric measurements as given in Table 3.

Table 3. Types of instrumentation for missile plume signature collection

Measurement Parameters	Type of instrumentation
Skin temperature, Thrust and chamber pressure of missile	Thermocouples, strain gauge, accelerometer and pressure transducer
Position of missile (XYZ and Pitch, roll and yaw)	Radar/GPS receiver, Telemetry, Optical tracker
Temporal, spectral, spatial and aspect angle of plume	Radiometers/ spectroradiometers, calibration sources
Temperature, humidity, scattering coefficient, absorption coefficient and angular scatter functions	Radiosonde, transmissometer, Rawinsonde rosol particle counter and polar Nephelometer

6. BACKGROUND CLUTTER RECORDING

For declaring the detected signal as a possible threat, the point source detected at a given time t has to be tracked continuously. The measured and derived parameters from this trajectory have to be compared with the built in database for declaring the emitter as a threat or non threat. Sensor noise is the random fluctuation in the output of a sensor which is normally a constant input to the sensor. Background clutter, on the other hand, produces variation in the output of the sensor associated with actual temporal or spatial variability in the background signal. Background clutter is frequently included as a noise source for purposes of stating missile plume signature (MPS) measurement accuracy. Clouds contribute to clutter in a sky background and complexities in a ground scene contribute to clutter for an earth background. Background clutter contributes an error in a MPS measurement. Background clutter "noise" is introduced into the MPS measurement when a background measurement is made as a means of estimating the background contribution to the MPS measurement. For example, a MPS measurement may be made with the missile in the sensor field of view. A separate measurement may then be made of the background alone so that the contribution from the background may be subtracted from the missile measurement. The background-only measurement may differ from that of the actual background contributing to the MPS measurement of the missile because of spatial or temporal variations in the background measurement. Further, the background measurement will also contain instrument noise. Repeated background measurements may be used to establish the net RMS variation caused by both noise and clutter in order to support both test design and post test data analysis. Background clutter must be considered as part of the MPS measurement design. Figure 3 shows sample MWIR clutter background for a tracking imager.

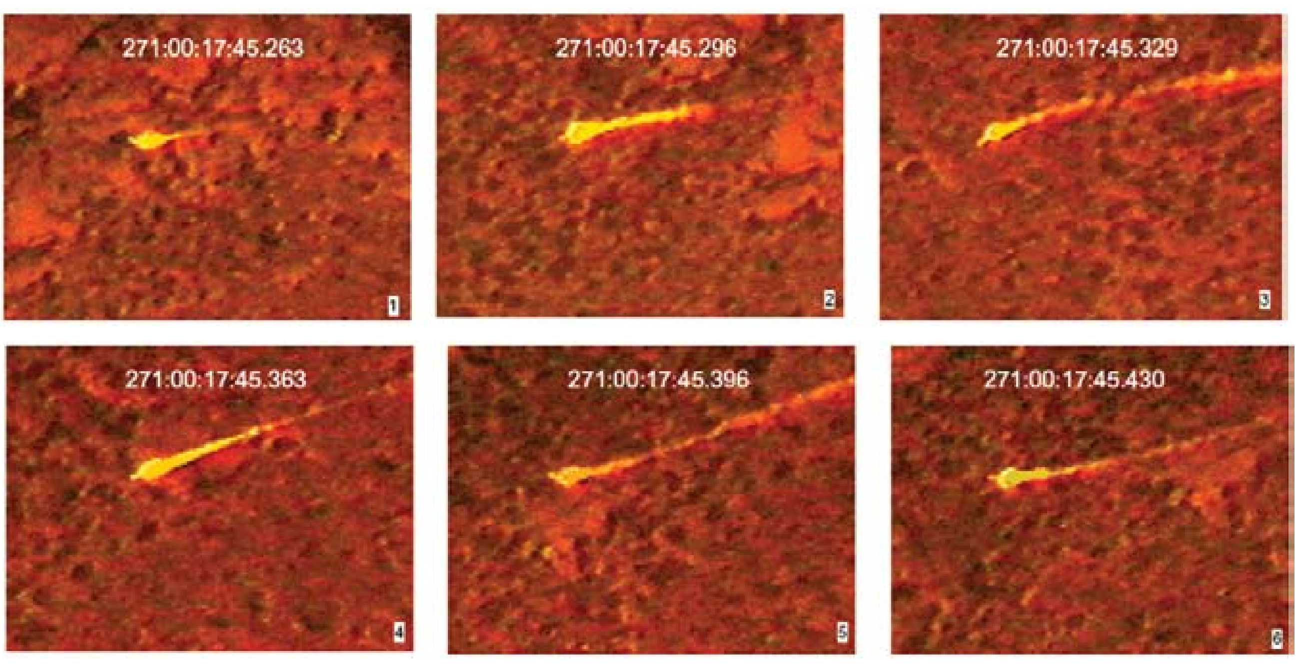

Figure 3. Sample MWIR clutter background for tracking imager[2].

6.1 Signal, Noise, and Clutter Considerations

The SNR of an instrument's measurement is the ratio of the background-subtracted missile irradiance to the NEI or NESI of the instrument. The signal-to-clutter ratio (SCR) is the ratio of the background-Subtracted missile irradiance to the true RMS variation in the background. As previously mentioned, background measurements actually contain the joint result of both clutter and instrument noise so that the ratio of the background-subtracted missile irradiance to the measured RMS background variations is the actual ratio that controls measurement quality. Twice the measured RMS variations in the background are called the background subtraction uncertainty as used in the error tree analyses. Often, when there are insufficient measurements to characterize the true RMS value, the background subtraction uncertainty is quantified as equal to one-half of the peak-to-peak excursions[5].

The methodology that needs to be adapted for MPS measurement is summarised in Fig. 4. During the measurement the uncertainties should also have to be addressed. The process of measurement is the making of a quantitative comparison between two or more states of a physical observable such as length, time, temperature, or spectral radiance. When one of those states is from a physically realizable national or international standard, then the measurement is an absolute one. Calibration is a special form of measurement to allow such comparisons. Absolute radiometric measurements require absolute calibrations. The three instrumental performance parameters are the instrumental responsivity (the gain or the output per unit input), the detectivity (the inverse of the noise equivalent irradiance), and the reference level or radiation at the entrance aperture. Complete specification of the uncertainties in the calibration measurement results must be given. The importance of measurement uncertainties and the frequent neglect of adequate error analysis warrant a review of the fundamental concepts that is followed in the MPS measurement.

7. BACKGROUND IR SIGNATURE COLLECTION

Detecting and segregating the missile threat amidst the IR background is a challenging task. This task can be successful only if the system is taught about the background IR in addition to the missile IR signature and trajectory. With respect to the tracking, the change in the background with spatial and temporal variation of the missile towards the target aircraft is the heart of missile warner system algorithm. Once the track is started, the background needs to be subtracted regularly to isolate the missile threat. The database being loaded on the system should be supplied with sufficient background data.

This task can be accomplished by installing the system on a test bed aircraft. The target aircraft should be fitted with onboard INGPS whose input should be fed to the system for getting positional information of the background scenario. The dual colour IR based missile warning system can be installed on the target aircraft. The best operable solution would be to use a Pod. The sensors can be fitted on the pod. The INGPS, processor and recorder can be mounted inside the pod. In this case, it would be very difficult to use a radiometer as the range and qualification play a major hurdle for recording. However, if one such radiometer is identified which can record IR signatures over the range and airborne qualified, the same can be installed in the pod and simultaneous output from the sensors and radiometer has to be recorded in the recorder separately. Each frame should be tagged with positional input from INGPS. This collection of data should be identified with each source and area. The collection of background need to be done at different altitude, different times in a day, different weather conditions and different terrain conditions. All these data need to be fused, a computer model need to be evolved for consolidating the entire data set into few buckets. So, in the actual system algorithm, after deciphering the trajectory information in relation to its features, the computed and measured data need to be compared with these recorded buckets for confirming whether the detected emitter is a threat or false threat.

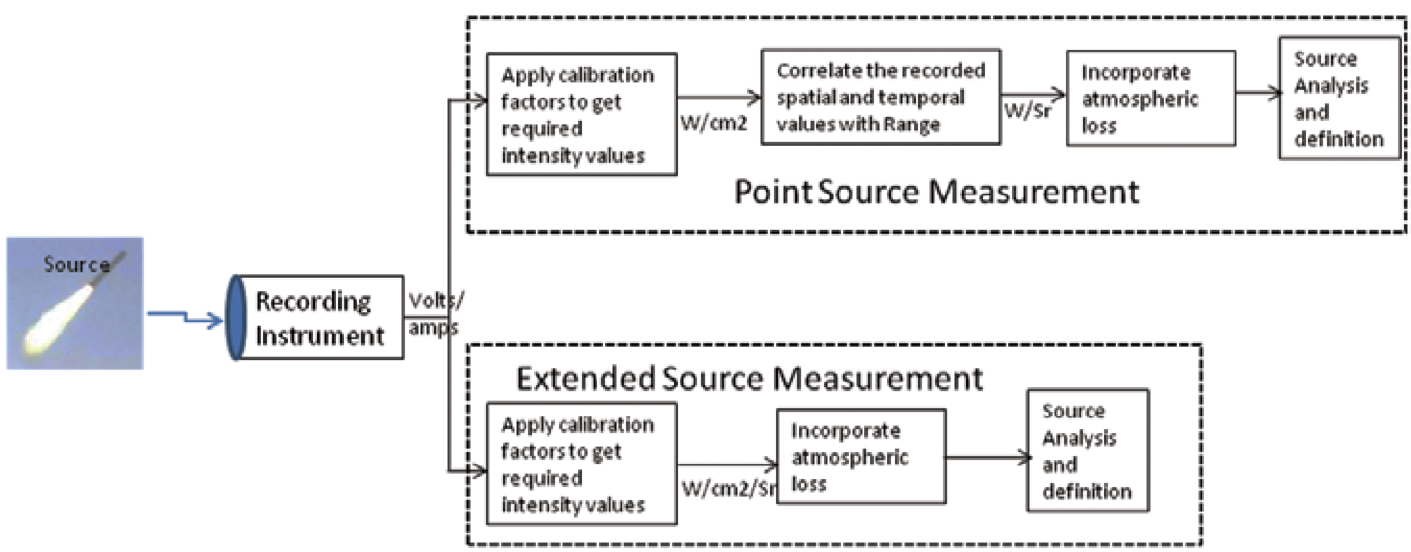

Figure 4. Methodology for collection of MPS data.

8. CONCLUSION

The effectiveness and the accuracy of the data of missile plume signature and the background in the dual band of IR (3 μ – 4 μ and 4 μ– 5 μ) can only ensure the performance of dual colour missile warning system. Though few theoretical models are available in the literature for predicting the IR signature on any background and for any missile (if the nozzle, chamber pressure and fuel details are known), the actual recording of the data only will increase the authenticity of the data. Therefore a combined effort need to be put for the collection of these data with members from services, R&D sectors and industrial partners for making this process a successful. The collection and maintenance of this data bank will be a regular task even after the system is proven by installing on the platform. Hence the task force with one establishment as the nodal agency would help the program of development of missile warner system a success.

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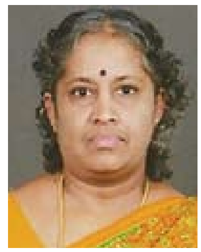
CONTRIBUTORS



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