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Test and Evaluation of Flight Vehicles using IR Imaging Techniques

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Abstract: Test and evaluation of flight vehicles play a significant role towards the successful validation of various design criteria of the flight vehicles. Analytical studies, design simulation, simulated performance validation with respect to various critical design parameters provide the basic level of design qualification. However, for the final validation of the flight vehicle performance, it requires a number of flight tests. During the actual flight test, the real time performance of the flight vehicle is monitored through a number of instrumentation systems. Infrared Imaging with its feature of real time image formation, detection of least temperature wrt background, real time image processing, automatic target detection and tracking play a crucial role towards the evaluation of flight vehicle performance. In the present paper, a detailed analysis has been performed regarding the IR camera and its possible application for test and evaluation of flight vehicles. A number of real time image processing methodologies are also discussed as a part of automatic target detection and tracking. Further, a brief introduction to IR radiation, transmission and IR sensors are also covered in the present paper. The principle of infrared target detection and various automatic tracking algorithms are explained in detail. Finally, the role of infrared imaging for providing various parameters of the vehicle during the flight trial is explained.

Keywords: Test & evaluation, EOTS, infrared imaging, infrared sensor, centroid, edge, correlation, tracking, SNR, MWIR, LWIR, ROI.

1. Introduction

Infrared radiation consists of electromagnetic waves in the wavelength region from 0.7µm to 100µm. It lies between the visible and the microwave portion of the electromagnetic spectrum. The primary source of infrared radiation is heat or thermal radiation. Even a very cold object, such as ice cube emits infrared radiation. A thermal imaging camera records the intensity of radiation in the infrared part of the electromagnetic spectrum and converts it to a visible image. Due to the propulsion and the surface heat of the flight vehicle, it gives very good IR signature. So, IR imaging system is used for tracking and providing the various real time video related parameters during the flight trial in a Test Range.

2. Test & Evaluation as Applicable to Flight Vehicles

Test & evaluation plays a measure role in the different developmental stages of the flight vehicle. The instruments in the Test Range help to reduce the development cycle by providing measurement of various parameters of the flight vehicle. In the final stage of the development and the deliverable version, the test and evaluation provides confidence in the performance of system. The test & evaluation procedure includes analytical study, laboratory test, analytical simulation, and finally flight testing in the Test Range. Even though there are number of simulations during the development, the flight test in the field against live target provides various critical parameters which are not possible obtain even with a number of laboratory tests [1]-[2].

3. Essential Parameters for Test & Evaluation

Trajectory information is the Time Space Position Information (TSPI). It gives positional information, velocity and acceleration of the target at a particular time in space. Behavioural information includes the pitch, yaw and roll rate. Health parameter includes surface temperature, pressure etc. Another significant parameter is the maximum range coverage and agreement of the trajectory with the nominal. Measurement of miss-distance between two targets is also very important parameter for the evaluation [1]-[2].

4. Tools for Trajectory Evaluation

A number of trajectography sensors are deployed in any typical Test Range for the flight evaluation. Radar provides the essential means for the trajectory evaluation. It operates both in skin as well as transponder mode, where it provides azimuth, elevation and the range information of the target with respect to its local reference.

However, it cannot provide tracking information for the low altitude targets due to ground reflection and multipath. There is also a risk of getting into the side lobe tracking. Using Global Positioning System (GPS), the trajectory of the vehicle can be ascertained. However, all these sensors depend on the on-board health of the flight vehicle and any failure on these systems will not provide the trajectory information.

Electro-Optical Tracking System (EOTS) is used in all the leading Test Ranges in the world in order to have the trajectography information even when the on-board system of the flight vehicle does not work. It is a multi sensor tracking system with infrared camera, visible camera and high speed video. It tracks the target using automatic video tracking algorithms. It can track the vehicle till the visible limit as provided by the sensors. It is a passive tracking system. At any point of time, the system can provide the azimuth and the elevation of the target from the system position. The positional information can be calculated using the azimuth and elevation information from multiple stations using the principle of triangulation. It has a multi-target tracking capability, by which it is possible to compute the miss distance. So, accuracy of the range instrument systems plays a vital role in the measurement of miss-distance. Electro-Optical Tracking System has various calibration methodologies to minimize the errors and it provides accurate data for the target [1].

5. IR Camera: An Essential Evaluation Tool

Target tracking by EOTS depends on the target video clarity. Due to the physics of working, IR camera becomes the most important sensor for tracking of flight vehicle. Compared to the visible camera, IR camera gives improved performance for long range tracking due to good IR signature of the target.

5.1 IR Technology

All objects above 0^{o}K emit radiations due to atomic vibrations. The wavelength of radiation depends upon the temperature of the object and its spectral emissivity.

Planck's equation was one of the milestones of physics which describes the spectral radiance *M(λ,T)* of a perfect blackbody as a function of its temperature and the wavelength of the emitted radiation, in the forms

$$M(\lambda,T) = \frac{2\pi hc^2}{\lambda^5}\left[exp\left(\frac{hc}{\lambda kT}\right)-1\right]^{-1} \text{ W/cm}^2\mu\text{m} \tag{1}$$

where λ is the wavelength, T the Absolute temperature, h is the Planck's constant, c is the velocity of light and k is the Boltzmann's constant.

Similarly, according to Wien's Displacement Law,

$$\lambda_{max}.T = 2898 \ \mu\text{m.K} \tag{2}$$

where λ_{max} is the wavelength of peak transmission.

Fig.1 shows the variation of spectral for blackbodies with wavelength [3]-[6].

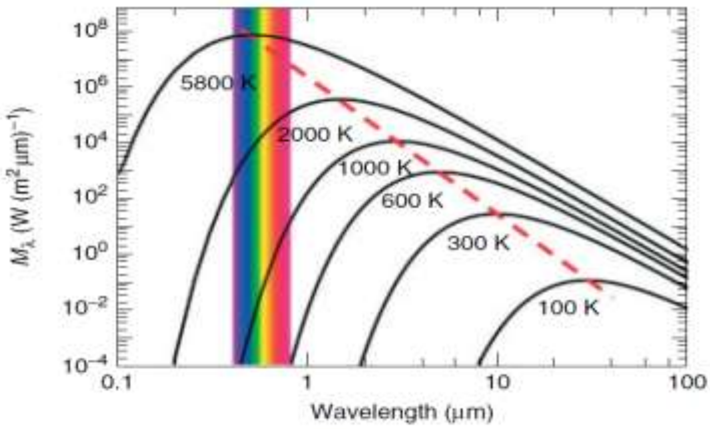

Figure 1: Spectral radiance *vs* wavelength

The significant characteristics of Infrared radiation are as follows:

- It is emitted by all bodies
- It is invisible to human eyes
- It has got long wavelength, hence it causes less scattering
- It also offers better transmission through various mediums

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Due to atmospheric absorption, all the wavelength of radiation cannot get transmitted in the atmosphere as depicted in Fig. 2 [7]. According to the atmospheric transmittance, the wavelength region from 0.7 to 1.4µm is often called as Near Infrared (NIR), from 1.4 to 3µm is Short Wavelength Infrared (SWIR), from 3 to 5µm is Medium Wavelength Infrared (MWIR) and from 8 to 14µm is Long Wavelength Infrared (LWIR) [18].

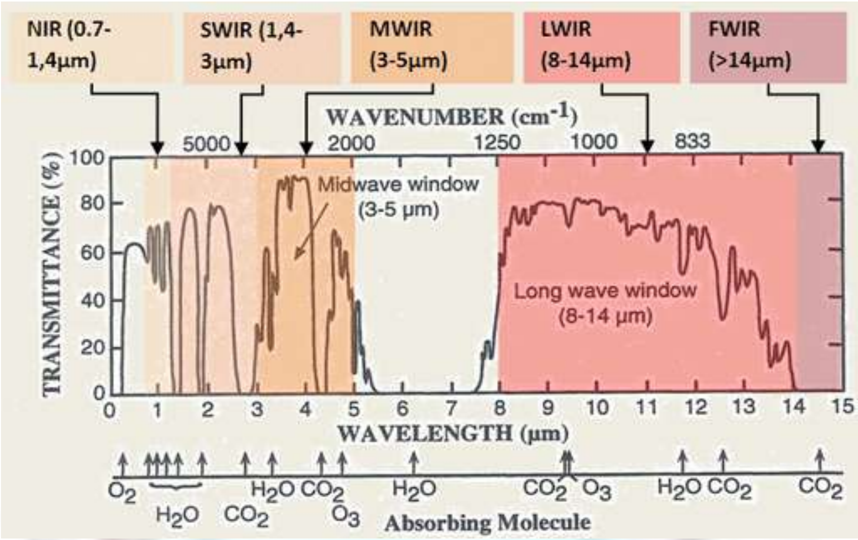

Figure 2. Atmospheric transmittance vs wavelength

From Fig. 3, it can be well understood that the peak of radiation for 8 - 14 µm (LWIR) occurs around 300°K whereas for 3-5µm (MWIR), the radiation peak is around 1000°K. Therefore, LWIR is used for imaging and security surveillance, where the objects are under normal temperature. MWIR is mostly used in the hot target tracking application, where radiation peak is at higher limits.

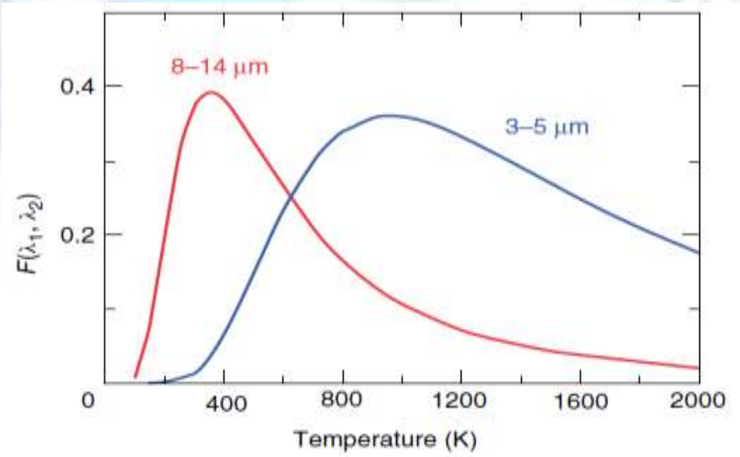

Figure 3: Portion of blackbody radiation in the wavelength of MWIR and LWIR

5.2 IR Sensors

There are two classes of IR detectors, one is photon detector and other is thermal detector. In the case of photon detector, the radiation from the target is absorbed in the detector material and is converted into the proportional electrical energy. The photon detectors show a selective wavelength dependence of the response per unit incident radiation power. They have very fast response and good signal-to-noise ratio (SNR). Photon detector requires cooling, which makes the detector expensive, bulky and heavy.

The second class of IR detector is the thermal detector, in which the incident energy is absorbed to change the temperature of the detector material, which changes some physical properties. This change in physical parameter is used to generate electrical output. The response of this type of detector is slow and generally wavelength independent. In contrast to photon detectors, thermal detectors are light weight and low cost. It operates at room temperature.

The important semiconductor materials for IR detectors are Mercury Cadmium Telluride (HgCdTe), InSb, PtSi, GaAs etc. Mercury Cadmium Telluride (HgCdTe) is the leading semiconductor for IR detectors. It gives reasonable performance in

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MWIR and LWIR. HgCdTe has better quantum efficiency and wavelength tenability. InSb is more matured and commercially available for MWIR. PtSi is most popular Schottky-barrier detector in the MWIR spectral range. Technology of GaAs is the most matured quantum well IR photodetectors (QWIPs) [3]-[6]. The relative sensitivity of various detectors at different wavelengths are depicted in Fig. 4 [17].

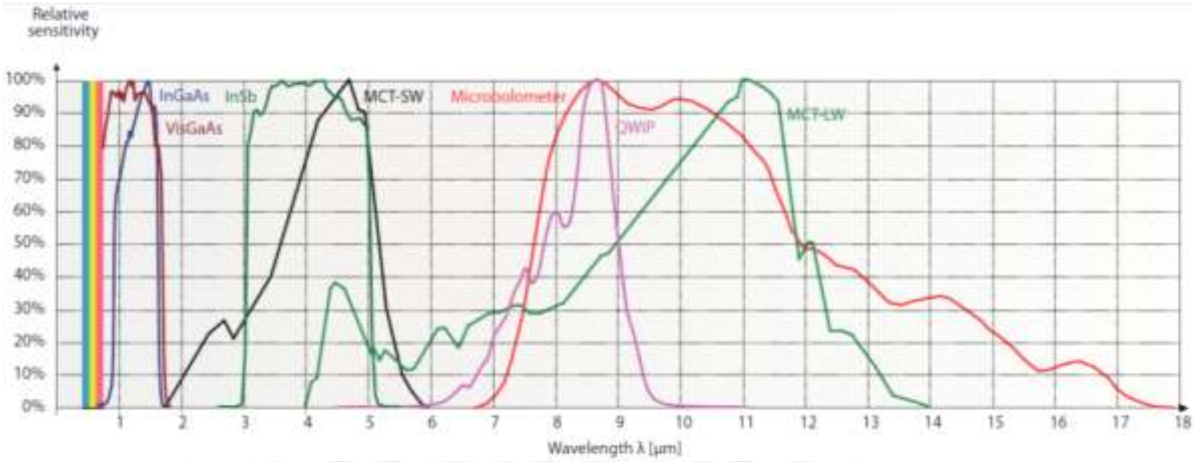


Figure 4. Relative sensitivity of various detector materials

5.3 Principle of Infrared Target Detection and Tracking

The block diagram of the system for target detection and tracking is shown in the Fig. 5. The IR radiation from the target or object is collected by the IR optics and gets focused on the IR detector. The detector unit converts the IR radiation energy into electrical charge or voltage. For a particular pixel value, the charge or the voltage is proportional to the intensity of the IR radiation of that point. So, IR image gets a function of the intensity of IR radiation at that point in the spatial coordinate. From the image, the region of interest (ROI) is identified using different image processing algorithms as given in literature [10][11][12][13]. Finally, the position of the target gets calculated and the offset of the target from the centre of the optical axis is generated. This offset is fed to the control unit for generating the condition of the auto track.

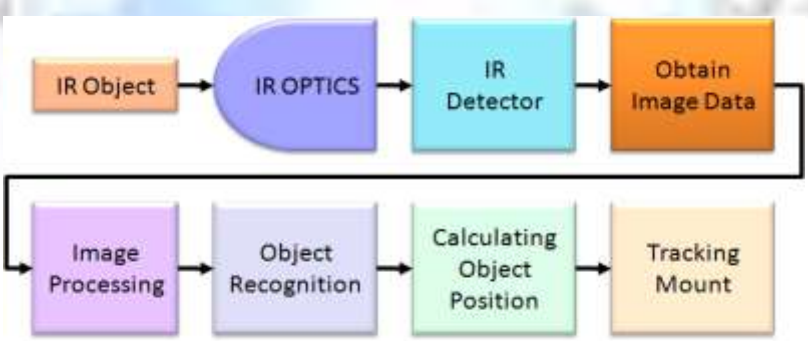
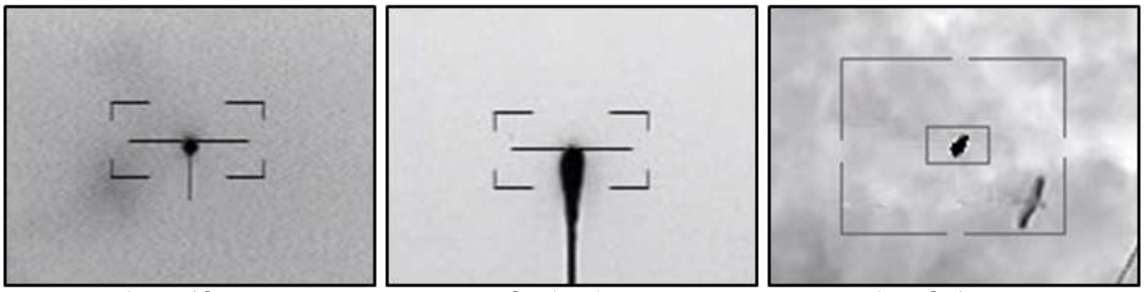


Figure 5: Block Diagram of the IR tracking system

6. Algorithms for Automatic Target Tracking

For the automatic target tracking, each field of the video is digitized and converted to binary image by applying histogram technique [8]-[10]. From the binary image, the target and the background is identified. Most popular algorithms for target tracking are centroid, edge and correlation. Centroid mode of tracking is used when the image is having good contrast and has uniform background. In the centroid mode, centroid of target is calculated and the tracking unit follows the centroid point. For an elongated target, the centroid mode of tracking fails due to the fact that the target as well as the plume together form a very strong IR image and the centroid computation is done for the entire virtual image leading to the failure of autotracking. In that case, the edge mode of tracking is used. In edge mode, the edge of the target is identified and used for tracking. The edge may be right, left, up, down, right-up, right-down, left-up and left-down. Suitable mode of edge tracking is used depending on the attitude and path of the target. Correlation mode of tracking is used when the target has a definite shape. It gives better performance in a clustered background than other conventional methods. In this method, the tracking is done by matching of the stored reference image from previous frame with the subsequent frame [11]-[16]. The various modes of tracking are shown in Fig.6.

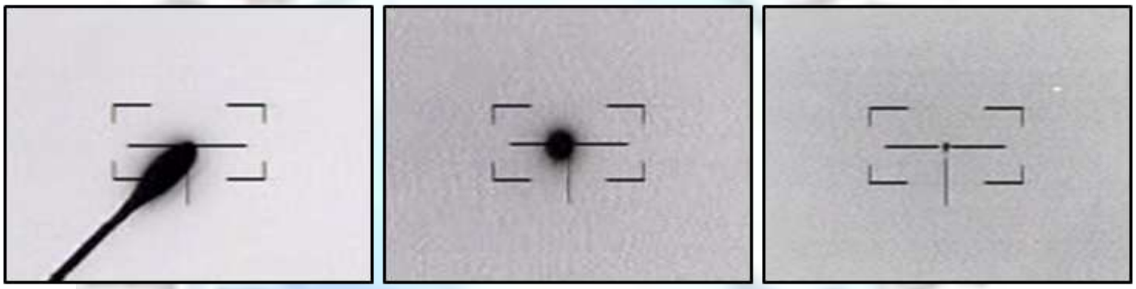


Centroid **Edge (Top)** **Correlation**

Figure 6: Modes of tracking

7. Significance of IR Imaging in Test & Evaluation of Flight Vehicles

In the domain of flight vehicle tracking, IR camera plays a major role. During the powered phase of the vehicle, it offers a very high IR contrast due to the performance of the propulsion system. It is due to this sensor that EOTS is able to provide the details about various critical events during the course of the flight. Due to the high sensitivity of the detector, the IR camera is able to provide the image of the flight vehicle for a considerable long duration thereby allowing the designers to have a detailed analysis of the performance of the article under test. Fig.7 shows the Thermal signature of flight vehicle at different ranges.



Short Range **Medium Range** **Long Range**

Figure 7: IR signature of flight vehicle at different range

In certain other scenarios, the video captured by the IR camera is very effective in the evaluation of interception analysis of two vehicles. In the multi target scenario, various critical events during the cross over are also monitored by the IR camera. IR signature of multiple targets captured within the same field-of-view are shown in Fig.8. The target signature changes with the type of the flight vehicle, aspect angle, range of target and the atmospheric conditions. Target signature is very important for the automatic tracking and the real time trajectory generation.

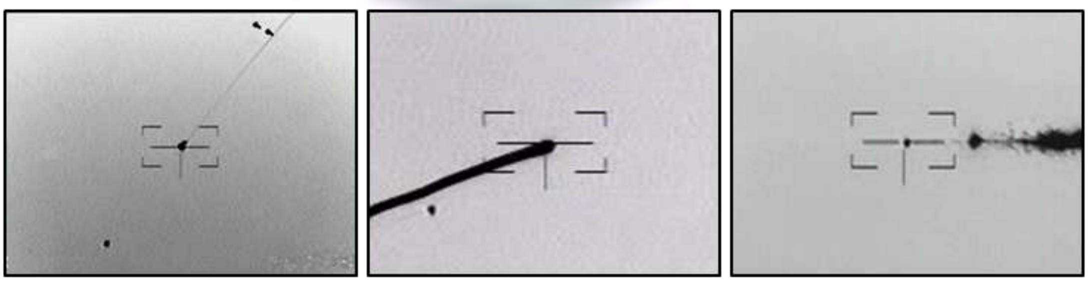


Figure 8: IR signature in multi target scenario

From the detailed study of the IR signature, it is possible to analyse the behavioral information of the flight. Due to the development of high performance optics for IR camera, it is also possible to evaluate the performance of various aspects of the article under test.

Conclusion

This paper describes the IR imaging technology and the working principle of IR Sensors. The different types of detector and the suitable detector for the test of evaluation of the flight vehicle has been discussed in detail. Principle of Infrared target detection and the different modes of tracking is also explained in detail. Performance of different tracking algorithms are explained and compared. This paper gives the approach towards implementation of IR imaging sequence and image processing algorithms for real time target tracking.

References

[1]. Dr. B K Das, "Test and Evaluation of Tactical Missile System Using Electro-Optical Tracking System", ITEA Journal 2009, 30: pp. 143-148.
[2]. William R.Mentzer, "Test & Evaluation of Land-Mobile Missile System", Johns Hopkins Apl tech. digest, vol-19, no.4,1998, pp.421-435.
[3]. Ronald G. Driggers, Paul Cox, Timithy Edwards, Introduction to Infrared and Electro-Optical Systems, ARTECH House, 1999.
[4]. A. Rogalski, Infrared Detectors, 2nd ed., CRC Press, 2011.
[5]. M. Vollmer, K.P. Mollmann, Infrared Thermal Imaging, WILEY-VCH, 2010.
[6]. Gerald C. Holst, Electro-Optcal Imaging System Performance, 3rd ed, SPIE Press, 2003.
[7]. H.W.Yates, J.H.Taylor, Infrared transmission of the atmosphere, US Naval research lab,1960.
[8]. Rafael C. Gonzalez, Richard E. Woods, Digital image processing, 3rded, Prentice Hall, 2007.
[9]. J.R.Parker, Algorithms for Imaging Processing and Computer Vision, 2nded, WILEY Pub.Inc., 2011.
[10]. Emanuele Trucco, Konstantinos Plakas, "Video tracking: a concise suevey", IEEE Journal of Oceanic Eng., vol.31, No.2, Apr-2006, pp. 520-529.
[11]. Emanuele Trucco, Konstantinos Plakas, "Video tracking: a concise suevey", IEEE Journal of Oceanic Eng., vol.31, No.2, Apr-2006, pp. 520-529.
[12]. Liping Lu, Junxue Geng, Tianren Zhao, "Research and analysis small infrared object detection track algorithm and its image processing technology", 3rd International Conference on Computer Research and Development, 2011, IEEE Conference Publications, pp. 30-33.
[13]. Alton L, Gilbert. Michael K. Giles, "A real-time video tracking system", IEEE Trans. on Pattern Analysis and Machine Intelligence, vol-1, Jan.1980. pp.47-56.
[14]. M. Singh, B.S. Chauhan, N.K. Sharma, "VLSI architecture of centroid tracking algorithms for video tracker", IEEE Proc. of 17th Intr. Conf. on VLSI Design, 2004, 1063-9667/04.
[15]. M.Murshed, M.A.Akber Dewan, Oksam Chae, "Moving object tracking - a parametric edge tracking approach", IEEE Proc. of ICCIT, Dec, 2009, pp.471-474.
[16]. Joseph G.Ellis, Kathleen A Kramer, Stephen C. Stubberud, "Image correlation based video tracking", IEEE proc. 21st Int. Confe. On System Engineering, 2011, pp.132-136.
[17]. http://www.flir.com
[18]. http://www.us.schott.com