

1.1 INTRODUCTION

In the military scenario, protection of military assets, both stationary and mobile, is of paramount importance. It holds true at the time of operations and peace time as well. During operations, the method of protection involves annihilating the approaching threat from adversary. In peace time, the assets are vulnerable to detection by surveillance sensors on board platforms of relevance. In such scenario, the methods that provide protection to the military assets is commonly referred as Camouflage, Concealment and Deception (CCD) measures. Camouflage techniques are aimed to merge the assets in the background. Concealment methods are employed to hide the assets from the observation of adversary. Deception creates false signature of assets with an aim to fool the adversary on the presence of the original assets.

In target detection parlance, signature of an object is the characteristics of the object with which it is detected by a sensor system. The sensor system can be human eye, binocular, ultraviolet camera, night vision device, thermal camera, or radar depending on the electromagnetic region, which is required to be employed. Most of these systems, except thermal camera, records the energy reflected from the object. Thermal camera records thermal energy emitted from the object. The recorded image/ signal is utilised by the system for detecting the object in the given background. The contrast between the object and the background enables the detection of the object. By camouflage, the contrast is reduced so that the detection of the object becomes difficult from the given sensor system.

In case of military vehicle, its engine is the source of thermal energy, which gets manifested as exhaust emission. The exhaust region with high temperature is recorded by thermal camera distinctly due to its high thermal contrast with the background. In such cases, the methods of camouflage and concealment are insufficient to reduce the thermal contrast and hence probability of detection by thermal camera. Use of deception device that creates false signature is found to be effective in reducing the probability of detection by the thermal camera.

A deception device is a low cost, true-to-the-scale, look alike of the original object, which mimics the signatures of the original object. Essentially, it is a metallic structure made up of sheet metal with shape and size equal to that of the original equipment. To mimic signatures in all the EM regions except thermal region is relatively easy. The thermal signature of the object depends on temperature and gaseous content of the exhaust emission of the object. A detailed analysis of the exhaust gas emission is essentially required to simulate the same in the deception device.

1.2 PURPOSE OF THE STUDY

In defence applications, military deception is an important aspect of modern warfare. Most of the defence equipments during past wars have been destroyed by the IR guided weapons. Therefore, it has necessitated the selection of research area, which enhances national defence capability. Two general use diesel vehicles such as Truck and Bus have been subjected

to thermal signature study and analysis of exhaust emission. Same methodology of thermal signature analysis of exhaust emission can be extended to ground based military vehicles such as Tank, Armoured personnel vehicles (APCs) and Gun. The outcome of the analysis will be utilised in the development of decoy of military vehicles with similar thermal signature simulation for military camouflage and deception. It will further help to employ suitable thermal signature suppression techniques. This work is very useful for enhancing survivability of the defence equipments.

Also, exhaust gases emission particularly NO_x analysis of diesel engine will be useful for determining contribution of NO_x to thermal signature. The approach is more practical in field conditions, where the standard test conditions and test equipments are not available. Thus, the research work will be very useful in the development of military decoys of military vehicles with thermal signature simulation of exhaust emissions in real field conditions.

Similarly, thermal infrared signature visualization of diesel exhaust emission scan gives quick indication about exhaust gases and unburned gases. The acquired thermal images of the exhaust of the diesel vehicle with comparison of the standard fuel burning thermal images may provide direct information about engine status. This information so derived is related to exhaust gases and will also be helpful in diagnosis of engine problems and performance. It will also give opportunity to find diesel engine faults quickly and taking advance measures for improving engine efficiency. This work can be considered in future.

1.3 RELEVANCE OF THE WORK

Nowadays, advanced sensors & surveillance equipment is capable of operating round the clock under adverse weather conditions. They have become serious threat to survival of troops & weapons [ATTP 3-34.39(FM 20-3)]. With the advancements in Thermal Infrared (TIR) technology, IR guided weapons are replacing the Microwave (MW) guided weapons and they are considered among the most threatening weapons. Therefore, research and development for thermal IR defence strategy has become very crucial and extremely important. It has been established that thermal IR signature simulated decoy are the most effective technique to confront IR guided weapons [Hesong H. *et al.*, 2017].

In the ground vehicle, thermal signature of exhaust emission plays the key role for detection and identification of the ground targets using thermal camera. Exhaust emission of ground vehicle reveals vital information, which makes it vulnerable to target detection and subsequent attack by heat seeking weapons. While other parts of the vehicle may be shielded for thermal radiation emission, exhaust emission remains open and causes recognition of the vehicle by thermal imaging system. Therefore, study and analysis of exhaust emission of diesel engine based vehicles has become prime importance area for research and development of decoy with thermal signature simulation considering the national defence security [Barreiros M., 2000].

Diesel engines are widely used in vehicles, loading trucks, cranes, dozers, generators etc. They play a vital role in transportation & power generation. Thermal signature study and analysis of diesel vehicles exhaust will be useful for testing of engine functioning and for controlling exhaust emission as well [Shi-gui L. *et al.*, 2011]. The study has relevance in both defence and civil sectors.

1.4 AUTHOR'S CONTRIBUTIONS

Thermal IR signature visualization of vehicle's exhaust emission and its analysis has become important area with the advent of advanced thermal imaging systems with round-the-clock operational capability. So far thermal IR signature analysis is carried out for high temperature gas emissions such as exhaust of aircraft plume and furnace. In the present research work thermal signature analysis of exhaust emission of diesel engine has been carried out in TIR (3-5 μm and 8-14 μm) regions of EM spectrum for most commonly used diesel vehicles in defence and civil sector such as Truck and Bus. Analysis of exhaust emission of the diesel vehicles along with their thermal signatures has provided important information. They are being used in the development of military decoys as per defence requirements. Thermal signature analysis of diesel exhaust emission will also be helpful for designing appropriate thermal signature suppression methods for camouflaging of the vehicles. Infrared imaging techniques for visualizing exhaust emission gas species will be a useful methodology to identify ground vehicles in enemy's territory. Also, NO_x analysis of diesel engine vehicles will be helpful to determine its contribution to thermal signature in real field conditions.

1.5 SCOPE OF WORK

Thermal IR signature analysis of diesel exhaust emission is important area for civil and defence sector. Proposed research work includes data acquisition and analysis of exhaust emission of diesel vehicles, visualization of thermal signature of the vehicles and analysis of exhaust emission using thermal imager in MWIR (3-5 μm region) and LWIR (8-14 μm) bands, feature extraction from the thermal images and computation of spectral radiance contribution of exhaust gas species in TIR signature using HITRAN database. This research work has highlighted the importance of thermal IR signature analysis of exhaust emission of diesel based ground vehicles.

1.6 STEPS ADOPTED IN THE RESEARCH WORK

The following steps have been adopted to accomplish the proposed research work.

1. Literature survey in the area of measurement of diesel exhaust emission, TIR signature measurement using thermal imager in MWIR (3-5 μm) & LWIR (8-14 μm) regions, simulation of thermal signature in military decoys and use of HITRAN database for determination of spectral radiance of exhaust gas emission.
2. Understanding the functioning, application and limitation of measuring instruments such as Portable Gas Analyzer, Thermal imaging system in MWIR and Hand held thermal imaging camera in LWIR.
3. Study of diesel emission norms and specification of selected diesel vehicles Truck and Bus for experiment.
4. Measurement of temperature and concentration of exhaust gas species in idle engine running and accelerated engine condition of Truck and Bus.
5. Measurement of thermal signature of exhaust emission of diesel vehicles in idle engine running and accelerated engine condition.
6. Computation of transmissivity of exhaust gases such as CO, HC, NO and NO₂ using Javahawks software for HITRAN database. Computation and analysis of spectral radiance of exhaust gas species using HITRAN database during idle engine running and accelerated engine running condition.
7. Compilation of results of thermal signature analysis of diesel exhausts emission and exploring their utility in military decoy design.

1.7 ORGANIZATION OF THESIS

The thesis is organized into nine chapters as per the following details.

Chapter 1 presents the introduction to the research topic and outlines the work plan to accomplish the research work.

Chapter 2 documents literature review on the topic of diesel exhaust emissions, portable gas analyzer, thermal signature measurement in MWIR (3-5 μm) & LWIR (8-14 μm) bands and computation of transmissivity of gas species using HITRAN database.

Chapter 3 deals with the methodology planned for measurement of exhaust gas emission, diesel exhaust emission norms, gas radiation, gas absorption and emission, experimental plan for thermal IR image recording, specification of thermal imager and gas analyzer.

Chapter 4 describes the thermal IR images of exhaust gas emission of Truck and Bus that were acquired using radiometric thermal imager in MWIR (3-5 μm) during idle engine running and accelerating engine condition. Thermal IR image analysis using Altair and ENVI software is also explained.

Chapter 5 deals with the calculation of spectral radiance of exhaust gas emission using HITRAN database during idle and accelerating engine condition of Truck and Bus. Spectral radiance of exhaust gas species CO, HC, NO and NO₂ is analysed in detail.

Chapter 6 describes the analysis of thermal IR image of exhaust gas emission using hand held thermal imager(HHTI) in LWIR (8-14 μm) during idle engine running and accelerating engine condition of Truck and Bus.

Chapter 7 presents the importance and application of thermal signature of exhaust gases emission towards Development of Mock-up (1:1 scale decoy) of combat Vehicle with thermal signature simulation.

Chapter 8 summarises and concludes the research work. It also includes application area of present work and recommendations for future work.

Annexure includes detailed analysis of exhaust gases emission (esp NO_x) contributions to thermal signature with respect to time under idle engine running and accelerating engine running condition of static Truck and Bus in field condition.

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