

Thermal IR Signature Study and Analysis of Exhaust Emission of Diesel Engine Vehicles

-Doctor of Philosophy

A Thesis submitted by
Ajay Jain

in partial fulfillment of the requirements for the award of the degree of
Doctor of Philosophy



॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

Indian Institute of Technology Jodhpur
Department of Mechanical Engineering
July 2021

Chapter 8

Summary and Conclusions

8.1 INTRODUCTION

This research work provides valuable information regarding thermal signature of exhaust gas emission of diesel engine vehicles which is very crucial for defence and civil applications. Thermal signature of exhaust gas emission of military vehicles can be observed and detected through remote surveillance devices such as thermal imager. The identification of individual gas species is not possible from thermal IR image of exhaust gas species. However, spectral radiance contribution of individual gas species can be determined using HITRAN database. The importance and necessity of exhaust thermal signature simulation in the military decoy of a combat vehicle is documented in Chapter 7. The NO_x emission measurement in real field condition and its analysis of diesel vehicles indicates the requirement of SCR retrofitting in old diesel vehicles, which will reduce the exhaust emission. This will ultimately result in reduction of thermal signature consequently it will reduce detectability of the diesel vehicles from the sensors of the adversary. The results presented in this thesis provide initial steps in this direction.

8.2 SUMMARY

The overview of entire study and research work is described below.

Thermal signature in terms of temperature and radiance of exhaust gas species CO, HC and NO_x of diesel vehicles such as Truck and Bus in idle engine and accelerating engine running condition were thoroughly studied and analyzed using thermal imagers in MWIR (3 - 5 μm) and LWIR (8 -14 μm) wavebands. The concentration and the temperature of exhaust gas species of the vehicles were measured using portable gas analyzer in real field conditions. The analysis of the thermal images and other measurements have revealed that exhaust gas species of diesel engine can be visualized by remote surveillance devices such as thermal imagers in MWIR and LWIR wavebands. Thermal signature of exhaust gas species is more prominent observed in MWIR image in comparison to LWIR image for the reason that most of the absorption and emission lines of the exhaust gases such as CO, HC and NO_x, belong to the MWIR waveband. Thermal signature of unburned hydrocarbon and soot particles gets recorded in the LWIR waveband. Experimental data illustrated that concentration and temperature of exhaust gas species of diesel vehicles are major contributors for generation and variation of thermal signature. The variation in concentration and the temperature of exhaust gas species of the vehicles are higher in accelerating engine condition than that in idle engine running condition. However, identification of individual gas species is not possible using Thermal IR imager.

The thermal radiance of exhaust gas species has also been measured using radiometric thermal imager in MWIR and its detailed analysis has been carried out with respect to time under idle engine running and accelerating engine condition of the vehicles. The spectral radiances of exhaust gas species CO, NO, NO₂ and HC were theoretically calculated using open source HITRAN computer data in MWIR (3 - 5 μm) waveband. The spectral radiances of the gas species were analyzed comprehensively with respect to average concentration of the gas exhaust species during idle engine running and accelerating engine condition. Study of thermal images and analysis of exhaust gas species data of the diesel vehicles using gas analyzer have

revealed that thermal signature prediction is possible in terms of two important parameters such as temperature and spectral radiance of gas. The spectral radiance contribution is maximum for CO and minimum for NO₂ in comparison to other gas species during engine idling and acceleration of Bus and Truck. It can be concluded that thermal signature of diesel exhaust gas emission as recorded by radiometric thermal imager is mainly due to CO. It is because CO has prominent thermal emission and absorption lines in MWIR (3-5μm) waveband.

Thermal IR image analysis has also been carried out in LWIR waveband. Based on that, it is concluded that thermal IR signature of diesel exhaust emission as recorded in LWIR waveband is due to unburned HC and soot particles. The thermal signature of the exhaust is more prominent during acceleration of engines of the vehicles.

The diesel exhaust emission particularly NO_x measurement and analysis has been carried out using Portable Gas Analyzer for Truck and Bus in real field conditions. It was observed that the exhaust emissions of both the older diesel engine based vehicles have NO₂/NO_x ratio less than 0.5, which is required for efficient retrofitting of SCR for reducing the exhaust emission. The 1993 model Bus has the NO₂/NO_x ratio of 0.3. The 1998 model Truck has the NO₂/NO_x ratio of 0.4. NO_x measured by sensor has higher value than the theoretically computed NO_x. It has been found that calculated error in percent (%) is about 30% & 35% for Bus & Truck, respectively. This provides important inputs for diesel engine retrofitting which will help in reducing the thermal signature of the exhaust emission of diesel vehicles. This will be beneficial from military point of view as the reduction in thermal signature of exhaust will result in reduced detectability of the diesel vehicle from surveillance sensors of adversary. This will also help in the design of military decoys with appropriate thermal signature simulation.

8.3 CONCLUSIONS

The entire study, experimental work and analysis indicate that

- (i) A new methodology has been established for thermal signature measurement of exhaust gas species of diesel engine based vehicles and its analysis. It is concluded that thermal signature visualization of exhaust gas species of diesel vehicles is possible using thermal imagers in MWIR (3-5μm) and LWIR (8-14μm) wavebands. The radiance of exhaust gas species mainly depends on concentration of gas species, temperature of gas species, thermal contrast and optical path length.
- (ii) It has been observed that variation in concentration and temperature of exhaust gas species of vehicles under accelerating engine running condition is more significant than that under idle engine running condition. This can help in maintaining appropriate speed of military troop movement to minimize the possibility of detection.
- (iii) The total radiance of exhaust emission has been measured using radiometric thermal imager. Individual contribution of spectral radiance of exhaust gas species has been determined using open source HITRAN computer data. The spectral radiance contribution of exhaust gas species is in decreasing order as CO, NO, HC and NO₂. Based on this, thermal signature simulation can be incorporated in the deception device of the military vehicles.
- (iv) The thermal IR image analysis of exhaust emission has provided useful information, which will be helpful for planning and implementation of thermal signature in the deception device of the military vehicles.
- (v) Presented methodology may be used for thermal signature measurement and finding out radiance contribution of individual species in high temperature exhaust emission of Aircraft using HITEMP database.

(vi) The NO_x emission analysis of diesel vehicles in open and real field condition may be the decisive factor for retrofitting engine using SCR technology for NO_x reduction as per present emission norms. It will be useful for exhaust emission control. More importantly, the SCR retrofitting will be beneficial for reducing the thermal signature of exhaust and achieve reduced detectability of the diesel vehicle from surveillance sensors of adversary.

.....

