Hand held hyperspectral imager for standoff detection of chemical and biological aerosols

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ABSTRACT

Pacific Advanced Technology has developed a small hand held imaging spectrometer, Sherlock, for gas leak and aerosol detection and imaging. The system is based on a patented technique, (IMSS Image Multi-spectral Sensing), that uses diffractive optics and image processing algorithms to detect spectral information about objects in the scene of the camera. This cameras technology has been tested at Dugway Proving Ground and Dstl Porton Down facilities looking at Chemical and Biological agent simulants. In addition to Chemical and Biological detection, the camera has been used for environmental monitoring of green house gases and is currently undergoing extensive laboratory and field testing by the Gas Technology Institute, British Petroleum and Shell Oil for applications for gas leak detection and repair.

In this paper we will present some of the results from the data collection at the TRE test at Dugway Proving Ground during the summer of 2002 and laboratory testing at the Dstl facility at Porton Down in the UK in the fall of 2002.

1 INTRODUCTION

Pacific Advanced Technology and our IMSS technology was one of several passive standoff detection systems that participated in the TRE field trials at Dugway Proving Grounds in the summer of 2002. For those trials we along with the US Navy (Dr. Elee Dumas of NRL) took two long-wave infrared IMSS systems (one cooled and one uncooled) and one mid-wave infrared system. The purpose was to demonstrate that passive standoff detection of biological agent aerosols was possible. Kaolin dust was used as an interferant and basilicas globules (BG) was used as the simulant for anthrax. Both the MWIR and LWIR IMSS systems were able to detect the BG simulant indicating the potential for passive standoff detection in biological warfare aerosol agent detection applications. The ability of the MWIR system to detect the BG cloud at a range of 3.5 Km at night is still not completely understood since there is no known absorption of BG in the mid-wave infrared. Additional works needs to be done to fully understand the phenomenology. There is a broad absorption band in the long-wave infrared and the IMSS was able to detect the aerosol cloud and measure the broad spectral absorption. In addition the Kaolin aerosol cloud was detected and showed a completely different spectral signature. Thus demonstrating the potential for the IMSS passive standoff detection system to be used for differentiating the Kaolin dust interferant from the BG anthrax simulant and being able to remotely identify a biological aerosol threat cloud.

Figure 1. The LWIR IMSS Systems.

In addition to the TRE trials the IMSS longwave infrared systems was taken to the MoD at Dstl Porton Down facility in the UK. In the Dstl laboratory different chemical warfare agent simulants were measured and the results of those tests will be presented in this paper.

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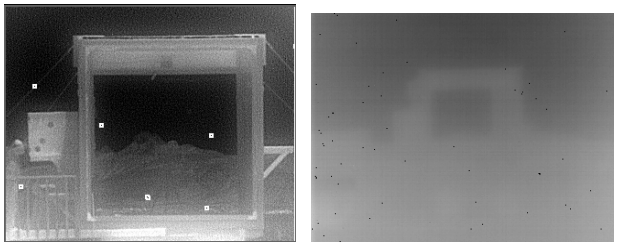
2 TRE FIELD TRIALS AT DUGWAY

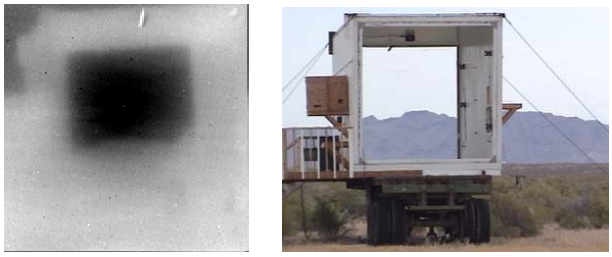
Figure 2. The Navy's MWIR IMSS System used at Dugway TRE trials.

In addition, a midwave infrared IMSS system was at the trials provided by Elee Dumas of NRL. A picture of the Navy's MWIR system is shown in figure 2 where the camera is an Indigo MWIR 256 x 256 InSb FPA coupled with the MWIR IMSS lens .

The TRE trials were designed for laser based systems. There were a few passive remote detection systems invited to the first week of the trials. The PAT systems and our team were one of those invited.



MWIR Uncooled LWIR



Cooled LWIR Visible Image

Figure 4. IMSS spectral images of the test chamber.

The IMSS technology participated in the TRE field trials at Dugway in July of 2002 and demonstrated the ability for standoff passive detection of the biological agent simulant BG. Shown in figure 1 are the two longwave infrared IMSS camera systems that were taken to Dugway, the one on the left uses an Indigo Uncooled microbolometer and the one on the right uses a cooled Cedip HgCdTe infrared camera loaned to PAT by Dstl for this test.

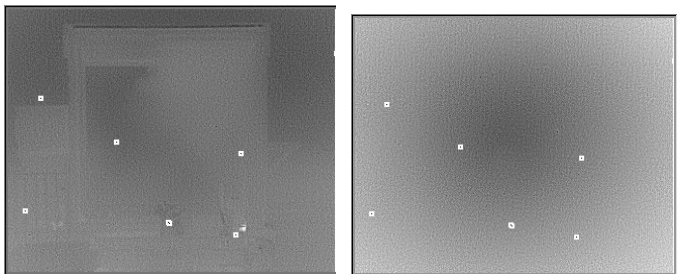
Figure 3. The PAT data collection system at Dugway.

PAT set up at the Dugway TRE field trials in a rented RV. All three data acquisition systems were inside the RV with the sensors sitting outside on tripods as shown in figure 3. Because the trials were designed for active systems, the ranges between the sensors and the disseminations were very long, but in spite of that, the PAT IMSS based systems were able to detect the biological simulants, BG, at 3.5 Km.

The sensors looked first at the interferant Kaolin Dust and anthrax simulant, BG, at a relatively short range in a large open air test cell. The test cell was at a range of approximately 50 meters. This cell was 3 meters high by 4 meters wide and 6 meters deep. Kaolin Dust and dry BG were blown into the test chamber, at separate times. Both the front and rear of the chamber were open. At the viewing position of the sensors both sky and mountains can be seen as background behind the chamber.

Shown in figure 4 are four images of the test

chamber taken with each of the three IMSS sensors and a visible camcorder. The different fields of view from the three different sensors can be seen. The MWIR sensor clearly shows the earth and sky background through the chamber (the white dots artifacts are caused by bad pixel). The earth and sky background are not as apparent in the two LWIR IMSS images. These images are raw images and have not had IMSS spatial processing applied (deconvolution of spatial cross talk caused by the IMSS lens effects). The two LWIR cameras were mounted lower than the MWIR camera and therefore there is more sky in the LWIR images due to the fact that they are looking up as compared with the MWIR camera which was looking mostly straight through the cell. The mountains in the background are at a significant range, thus offering a much lower spectral contrast to the species in the chamber as compared to the cold sky background.



4.9 microns **3.5 microns**

Figure 5. Kaolin dust dissemination as viewed with the MWIR IMSS system.

The atmospheric transmission in the MWIR spectral band is very absorptive below 3.5 microns due to water and CO_2 in the atmosphere. This can be seen by the spectral images from the MWIR IMSS system in figure 5. This image data cube was taken during the Kaolin dust dissemination which happened later in the day and the sun was behind a cloud as compared with the previous image in figure 4. The change in contrast is significant and can be accounted for by the fact that the sun was a large component in the MWIR spectral region, which is not present in the LWIR spectral region. The Kaolin dust being blown out of the disseminator in the lower right hand corner of the chamber can be clearly seen at 4.9 microns, in the left spectral image. Between 3.0 and 3.5 microns the atmosphere strongly attenuates the signal, as shown in the image on the right at 3.5 microns.

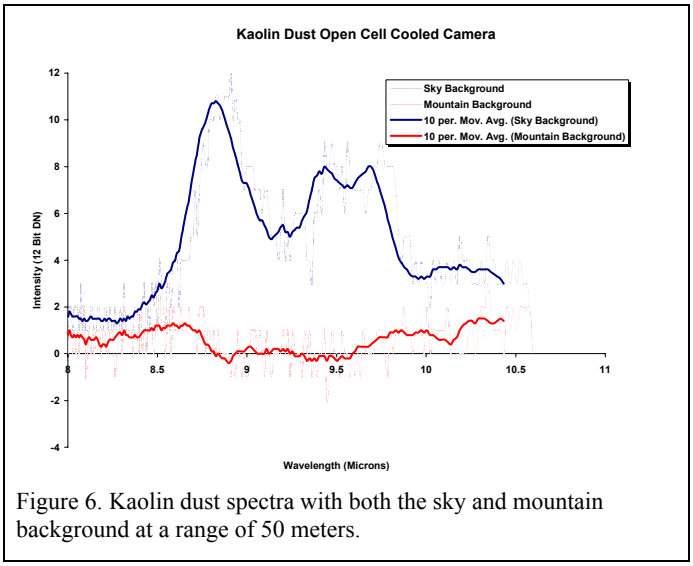


Figure 6. Kaolin dust spectra with both the sky and mountain background at a range of 50 meters.

The first release into the open cell was Kaolin dust at 2 pounds per minute with an air blower. Kaolin dust is a known interferant for biological aerosols. Spectra was collected for both sky and mountain backgrounds with all three IMSS systems (the cooled and uncooled LWIR IMSS systems, as well as the MWIR IMSS system). All spectra shown in this paper are the intensity difference between the species gas and the background. A data cube with no simulant was taken before and after each test. The background spectra before and after were compared to determine if any significant drift had accrued during the data collection period. This drift can be caused by both electronic changes and background intensity differences.

The spectra of Kaolin dust using the cooled IMSS system is shown in figure 6 for both mountain and sky background. There was good contrast with respect to the sky background and a good spectrum was generated. However, for the mountain background (mountain range was greater than 30 miles away), the signal to noise was too low to get a good spectra using the cooled Cedip camera system.

Shown in figure 7 is the same spectra along with laboratory spectra supplied by SBCCOM plotted as wavenumbers. The similarities are encouraging. The three peaks between 1150 and 950 wavenumbers are observed with the difference that the ratio between the peaks is reversed for the TRE test. The peak between 900 and 940

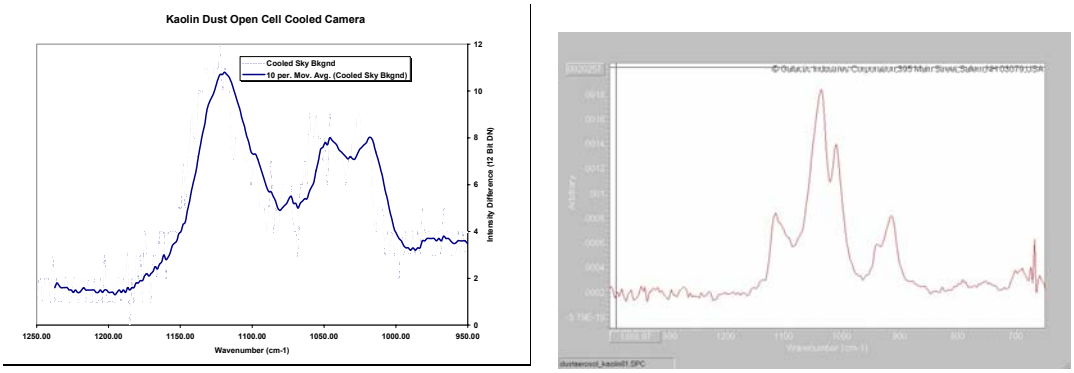


Figure 7. Spectrum as measured with the cooled IMSS system on the left and laboratory thin film Kaolin dust spectrum on the right.

wavenumbers is not seen by the cooled Cedip camera system because the spectral response above 10 μm (below 1000 wavenumbers) is very weak, the detector essentially cuts off at 10 μ m. However, this peak is observed using the uncooled Indigo camera system.

The signal to noise ratio for the uncooled system is marginal for the open cell gas test at a range of 50 meters. Kaolin Dust can be seen in the spectral image, but when creating spectra it is marginal at best. The spectra for a sky background for both the cooled and uncooled systems are shown in figure 8. (Keep in mind that the labels in the legend, the uncooled and cooled markings are reversed, the file was corrupted and we were unable to fix the text).

A few comments about these spectra in figure. Because the data was normalized, in order to compare on the same scale, the difference in sensitivity can be seen by the greater noise in the uncooled spectra as opposed to the cooled spectra. The cooled camera system had a lower signal to noise ratio, i.e. the cooled system had more sensitivity but also had more noise. The uncooled system had lower noise but less sensitivity.

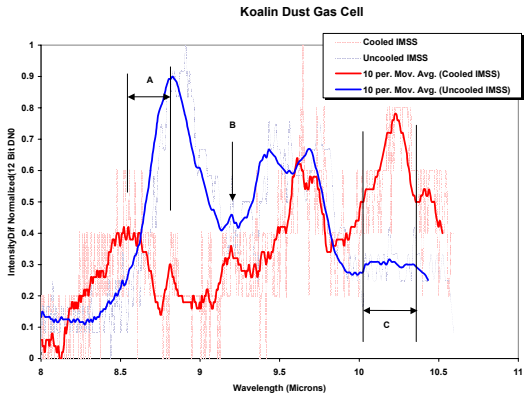


Figure 8. Kaolin dust normalized spectra with sky background from 50 meters range for both the cooled and uncooled system (note labels are reversed for the cooled and uncooled data).

The region marked as A in figure 8 is a region where the signal to noise for the uncooled detector was very low, actually there could be a peak that matches the cooled spectra if the sensitivity where better. There appears to be a shift to the shorter wavelengths. This could be caused by a calibration error. We did discover after the TRE trials that our calibration was in error due to an electronic problem with the motor controller. This was fixed before we took the system to the UK at Dstl, Porton Down.

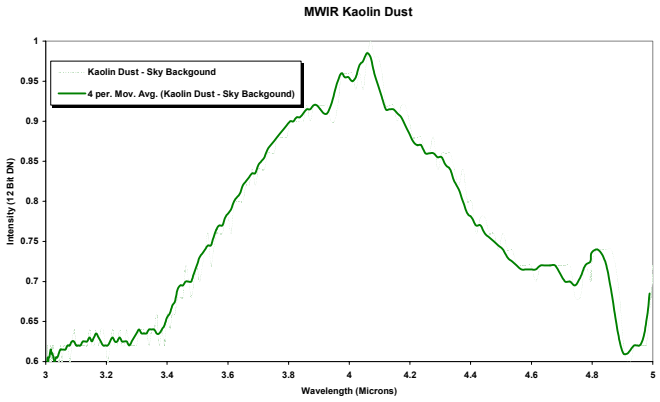


Figure 9. Kaolin dust in an open cell at a range of 50 meters as measured with the MWIR IMSS system.

The region marked B in figure 8 shows a small peak for the cooled system corresponding to a larger peak in the uncooled spectra, but the laboratory spectra does not show this peak. This maybe an atmospheric effect. The region in the cooled IMSS spectra marked C in figure 8 only shows a small peak, but remember the cooled system has very little response above 10 microns. Neither the cooled or uncooled cameras were ideal for a measurement across the whole spectral region from 8 to 11 microns. The uncooled system gave better performance above 9.5 microns. It is not understood why this is since the laboratory calibration showed that the uncooled system had good responsivity between 8 and 9.5 microns. It could be an atmospheric effect. None of these spectra have been corrected for the atmosphere.

The MWIR IMSS also measured the Kaolin dust in the open cell at a range of 50 meters. The spectra is shown in figure 9. We could not locate a laboratory spectra for Kaolin dust in the MWIR for comparison.

After the Kaolin dust test, BG was disseminated into the open test cell. Shown in figure 10 are the Spectra, as measured with the Cedip cooled IMSS for the open gas cell at a range of 50 meters with a sky background. A thin film laboratory spectra of BG supplied by SBCCOM is shown for reference. The peak between 8.75 and 9.5 microns line up fairly well between the lab and IMSS filed spectra. The shift to the shorter wavelengths for the IMSS spectrum can be accounted for by the poor spectral calibration before the trials. The match for the peak at 8 microns is not observed. There has been no compensation for atmospheric effects and that could explain why this shorter wavelength peak is not observed. The steeper decline at the longer wavelengths is most likely due to the spectral response of the detector which

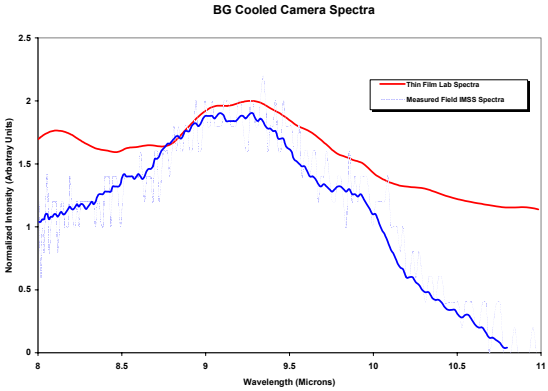


Figure 10. Cooled IMSS system measure BG spectra from open cell at a range of 50 meters, compared to a laboratory thin film spectra supplied by SBCCOM.

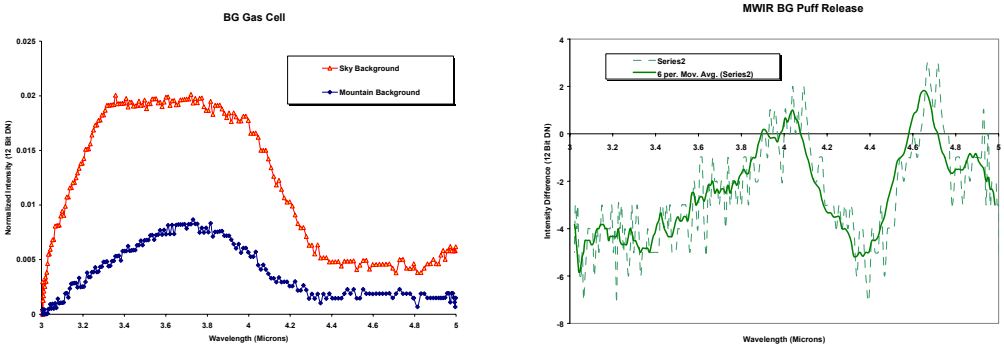


Figure 11. BG spectra of the open cell 50 meter range as measured with the MWIR IMSS system shown on the left and BG puff MWIR spectra taken with the IMSS MWIR at night at a range of 3.5 Km shown on the right.

strongly cuts off above 10 microns.

The MWIR IMSS system also measured the dry BG in the open path test cell. The spectra for both the sky and mountain background are shown in figure 11. As was the case for the LWIR spectrum, the better contrast was obtained with the sky background.

The MWIR IMSS system also measured the spectra for a BG puff release at a 3.5 Km range as shown on the right in figure 11. Comparing the 50 meter range, day time, MWIR spectrum for BG with the 3.5 Km MWIR BG spectrum taken at night that the signal appears to be in absorption at night rather than emission as was the case for the day time spectrum. At long range the signal below 3.5 microns is attenuated by water in the atmosphere (it was raining during this data collection sequence) and between 4.2 and 4.5 microns the absorption is due to CO_2 . The difference between the spectra taken during the day and at night, other than the atmospheric long path absorption, could be explained by some sort of scattering effect. During the day, when the sun is up, there is solar scattering and at night cold sky scattering or reflectance. The spectral image at 4.7 microns of the BG puff at 3.5 Km is shown in figure 12. The BG puff at night appears as a dark cloud in the MWIR spectral region.

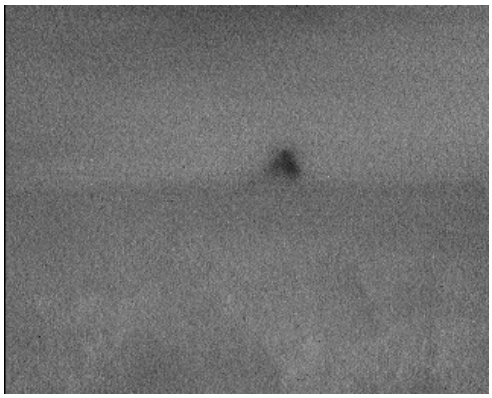


Figure 12. IMSS MWIR 4.7 microns spectral image of BG dry puff at 3.5 Km, 4 million particle per liter on Monday night 7/22/02.

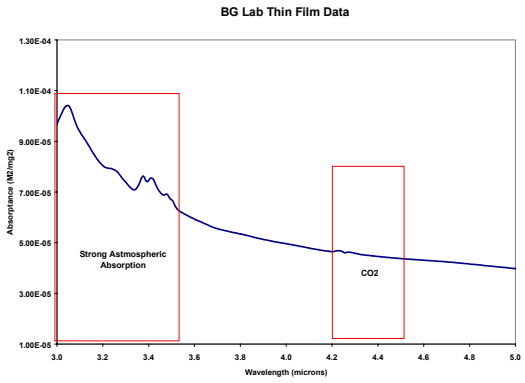


Figure 13. Laboratory thin film spectra of BG supplied by SBCCOM.

For reference the laboratory spectra of BG in the MWIR is shown if figure 13.

Unfortunately the LWIR cameras were covered during this puff release due to a rain shower in the area and we were not able to collect data at this time in order to make a good comparison between

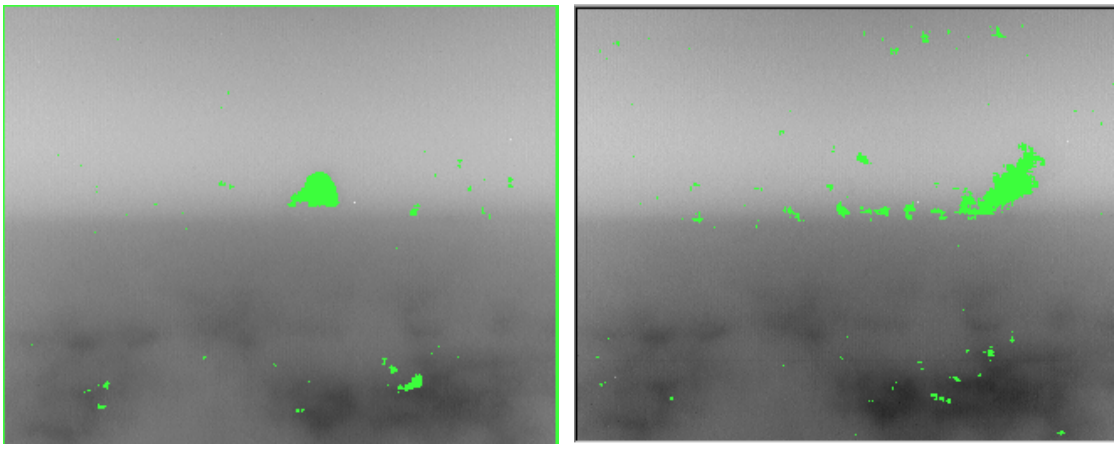


Figure 14. Dissemination BG cloud shown in green drifts out of the field of view within a few minutes.

the two bands.

The wind was blowing the BG gas cloud rather rapidly out of the field of view of the camera (5 degrees). Shown in figure 14 are two spectral images at 4.7 microns taken with the MWIR IMSS system. The images are taken 2 minutes apart. The gas cloud was detected with principal component analysis and is painted in green. The cloud can be seen at the horizon moving to the right in the scene.

3 TESTING AT DSTL PORTON DOWN

During the week of the 26th of August, Pacific Advanced Technology took two of our long wave infrared IMSS hyperspectral imaging systems to Dstl at Porton Down in the UK for the purpose of comparing cooled and uncooled technology, as applied to vapor phase chemical agent detection. Both the cooled and uncooled systems have a spectral resolution on the order of 6 wavenumbers. The IMSS lenses used for each of the systems was identical. For the uncooled technology the IMSS lens was attached to an Indigo Uncooled Merlin 12 bit infrared camera, which uses a detector array (320 x 256) that is made up of room temperature operating micor-bolometers. For the cooled technology, the IMSS lens was attached to a Dstl Cedip HgCdTe 128 x 128 14 bit camera cooled to 77 K. The Cedip camera was on loan to Dstl and was not representative of the best performing cooled longwave infrared camera. This camera had considerable noise that was not apparent when using a broadband lens, however, with the narrow band of the IMSS, the noise did limit detection performance. In spite of these difficulties, reasonable data was collected for different vapor phase chemical agent simulants.

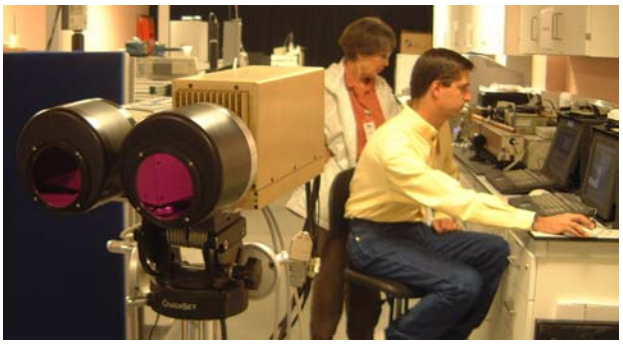


Figure 15. The two longwave infrared IMSS Hyperspectral cameras, along with the data acquisition system in the background, in the laboratory of Dstl at Porton Down. ***Crown Copyright 2002, permission to publish from Dstl.***

A picture of the two IMSS lenses attached to the two cameras is shown in figure 15. The two cameras were mounted on a single tripod and bore sighted. The two field portable computers in the background were each equipped with a frame grabber that was adjusted to synchronize with the tuning of the IMSS lens during data collection. In addition to the IMSS systems, a Bruker FTIR collected spectral data at the same time.

Several different chemical agent simulants were measured: dymethylmethylphosphonate (DMMP), methylsalicylate (MS), ammonia (NH_3), sulfurhexafloride (SF_6), and Freon. The DMMP and MS were vaporized from a liquid phase by placing them in a dish on a hot plate that was heated to 100 degrees C as shown in figure 16. The dish was placed in a fume hood with a black painted ambient temperature background. The IMSS systems were located at a range of 3.9 meters.

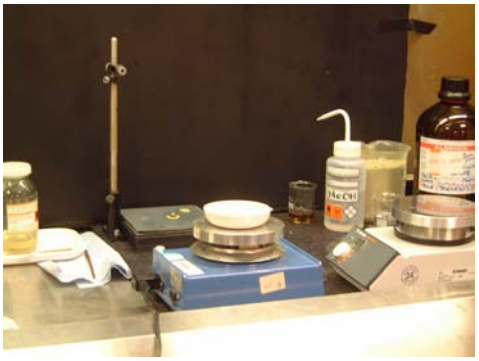


Figure 16. Arrangement for vaporizing the DMMP and MS. ***Crown Copyright 2002, permission to publish from Dstl.***

In addition to measuring the warm vapor phase emission spectra, we also measured ambient temperature gas absorption and cool gas absorption. For this, two gases

were entrapped in bags, and a 100 degree C hot plate was used as the source for absorption. Then cool gas, released from canisters, absorbed ambient temperature from the back wall of the fume hood. MS was vaporized and 2 ml was placed into a bag mixed with ambient air. Freon that was supplied by Bruker was also placed in another bag. For these two cases a hot plate was placed behind the bag and spectral image data was collected.

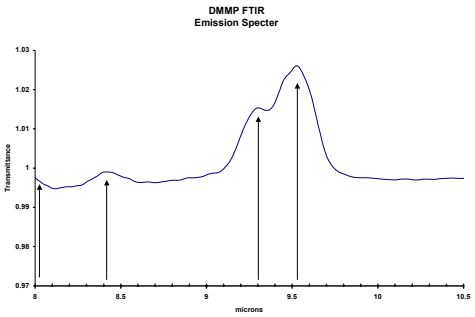


Figure 17. DMMP spectra as measured by the Bruker FTIR.
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NH_3 and SF_6, released from pressurized canisters under the fume hood, and spectral image data was collected on those as well. We were able to measure emission from a warm vapor, absorption with a hot background and absorption with an ambient background. In addition to the IMSS cooled/uncooled spectra, the Bruker FTIR spectra measured at the same time is shown. For some gases NIST spectra is shown as well. The Bruker FTIR emission spectra of DMMP is shown in figure 17.

A spectral image at 9.5 microns taken with the IMSS cooled system is shown in figure 18 on the left. The vapor can be seen (much more visible in a moving picture) as a gray cloud above the dish. A spectral image taken with the uncooled IMSS hyperspectral system is shown in figure 18 on the right. The vapor can be seen as a smoky gray cloud above the dish. The difference in the field of view between the two systems can be seen in these images. A point in the cloud was tracked to insure the vapor was selected throughout the data cube and a spectrum was plotted for these tracked pixels. A comparison of the IMSS spectra after spatial and both spatial/spectral deconvolution are shown in figure 19 on the left.

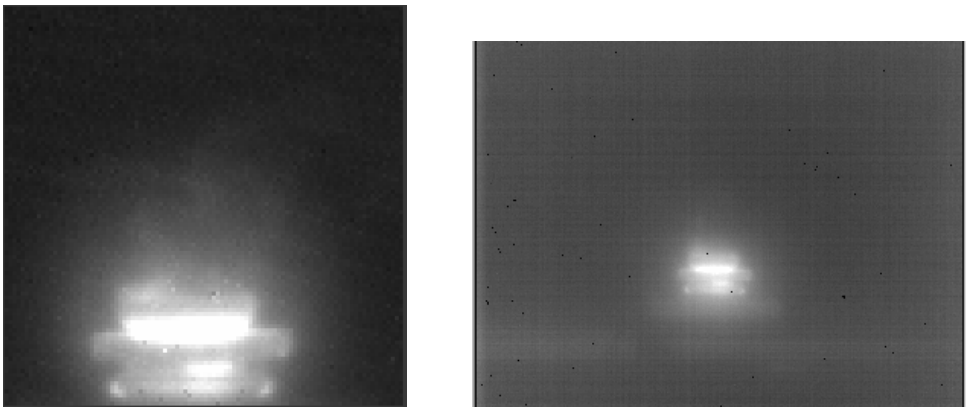

Figure 18. DMMP in vapor phase at 9.5 microns as imaged with the IMSS cooled camera system.

The IMSS uncooled system also measured the same DMMP vapor at the same time and the processed spectra for two different track files are shown in figure 19 on the right.

The vapor phase spectra of MS, as collected with the Bruker FTIR, is shown in figure 20 on the left and as supplied by NIST shown on the right.

MS vapor was measured with the cooled and uncooled IMSS system and is shown in figure 21, the cooled IMSS system spectra is shown on the left and the uncooled IMSS system spectra is shown on the right. The signal to noise for the uncooled IMSS system is much lower than the cooled system.

NH_3 was placed in a bag with a hot plate behind the bag and the spectra was measured with the IMSS cooled and uncooled systems simultaneously. The spectra, as measured with the Bruker FTIR, is shown in figure 22 on the left,

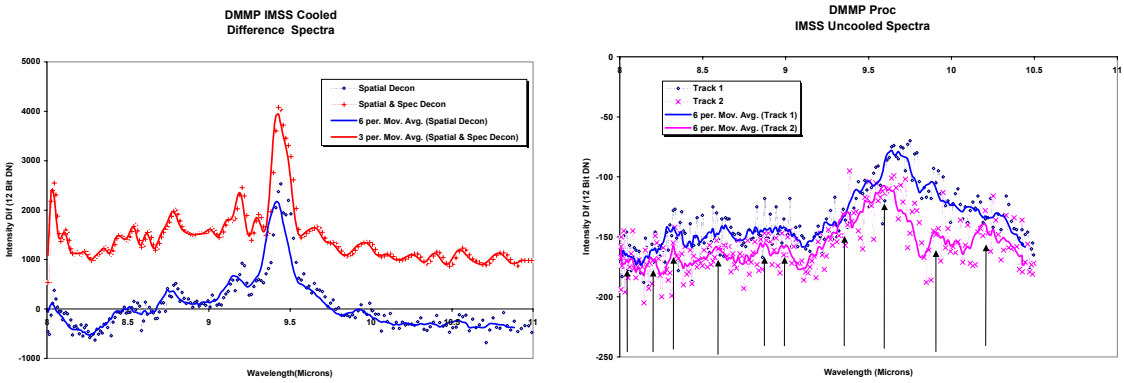

Figure 19. Spatial and Spatial/Spectral processed spectrum of DMMP as measured with the cooled IMSS system shown on the left, DMMP spectra as measured with the uncooled IMSS system is shown on the right.

and the NIST spectra for HN_3 is shown on the right. There are two very strong lines between 10 and 11 microns. The Bruker FTIR has picked these lines up as well as the other structure between 8 and 10 microns. The cooled IMSS system cut off at 10 microns so it was not able to see the two sharp lines above 10 microns. However, the cooled IMSS system was able to pick up the broad absorption dip from 8.5 to 10 microns as shown in figure 23 on the left. The uncooled system shows the same broad absorption between 8 and 10 microns as indicated in figure 23 on the right. For some reason the uncooled system was not able to detect the narrow absorption lines between 10 and 11 microns. The reason that the uncooled system, which should have spectral response out to 11 microns, didn't

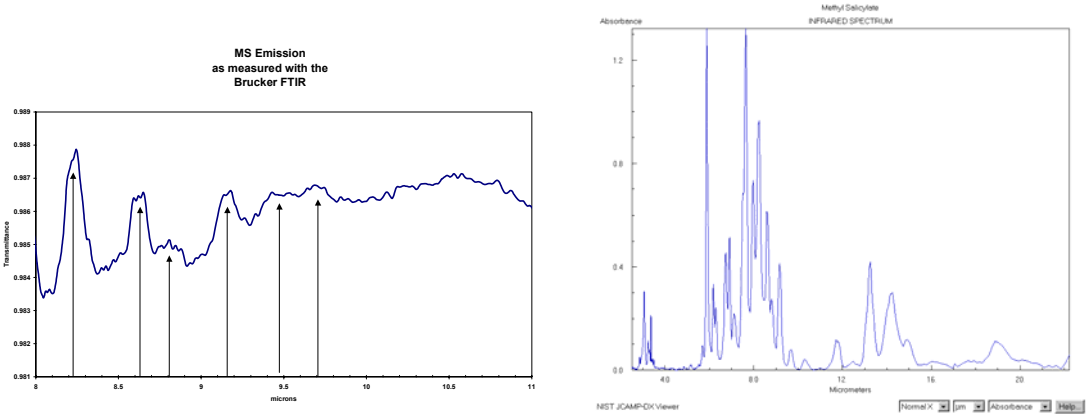

Figure 20. Spectra of MS as measured with the Bruker shown on the left and from NIST on the right.
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detect these strong lines is not understood at this time.

Clearly, from these data the cooled IMSS longwave system has more sensitivity than the uncooled IMSS longwave system. As a whole the results of the data reduction were quite encouraging. Using the cooled system, in spite of the noise in the camera and the cutoff at 10 microns, good spectra were collected for most of the gases.

Both the cooled and uncooled IMSS systems were able to detect the same peaks that the Bruker FTIR measured for DMMP. We were not able to obtain a spectrum of DMMP from NIST for this gas. However, the results for IMSS looked very encouraging. The cooled system had a much better signal to noise than the uncooled system as expected, but at close range both system can detect and identify this gas.

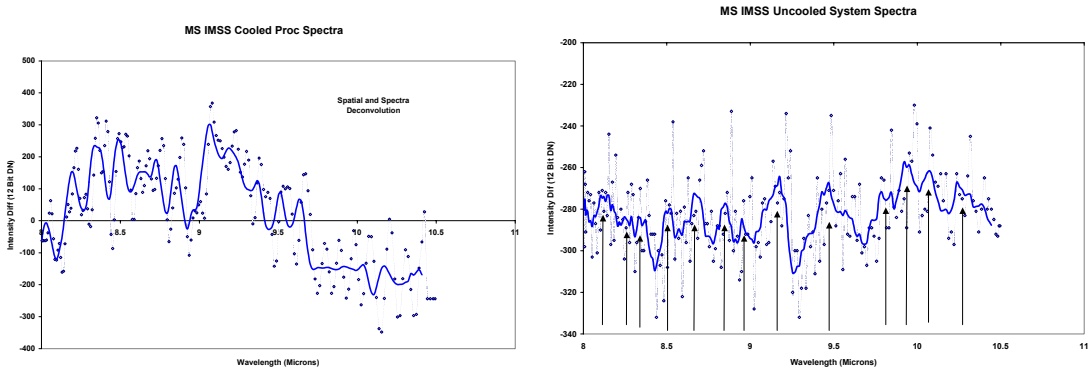

Figure 21. Cooled IMSS spectra of MS after spectral and spatial deconvolution and uncooled spectra on the right.

For the MS vapor phase we were able to obtain a NIST spectrum. Both the cooled and uncooled systems were able to detect and identify the spectrum of MS. Again, the cooled system had a better signal to noise than the uncooled system.

In looking at the absorption spectra of NH_3 the Bruker FTIR was able to detect the line around 10.5 microns as well as many smaller lines at the shorter wavelengths and the overall broad absorption between 8.5 to 10 microns. Due to the fact that the cooled IMSS camera cut off at 10 microns it was not able to detect the strong absorption lines around 10.5 microns. However it was able to detect the overall broad absorption between 8.5 and 10 microns. The signal to noise for this cool gas against the ambient temperature background was not as good as for the warm vapor phase emission spectra. The sensitivity can be improved with a lower noise infrared sensor. The noise in the Cedip camera was quite high.

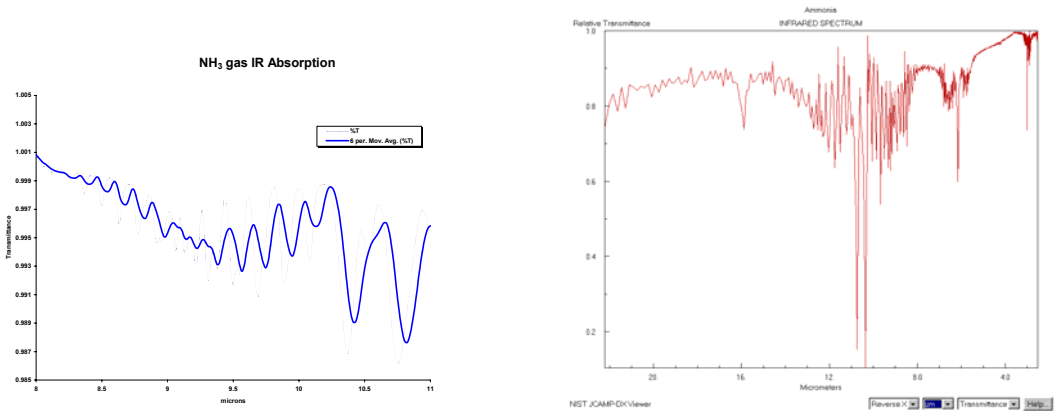

Figure 22. Bruker Spectra of NH_3 on the left and NIST spectra on the right.

The uncooled IMSS was also able to detect the broad absorption lines between 8.5 and 10 microns. It did not detect the strong absorption lines around 10.5 microns. Why this is, is not well understood at the moment. The calibration of the uncooled system indicated that it had reasonable response at 10.5 microns. It might be that the signal to noise of the system was just not good enough to detect the low contrast ratio of the cooled NH_3 with respect to the ambient temperature background.

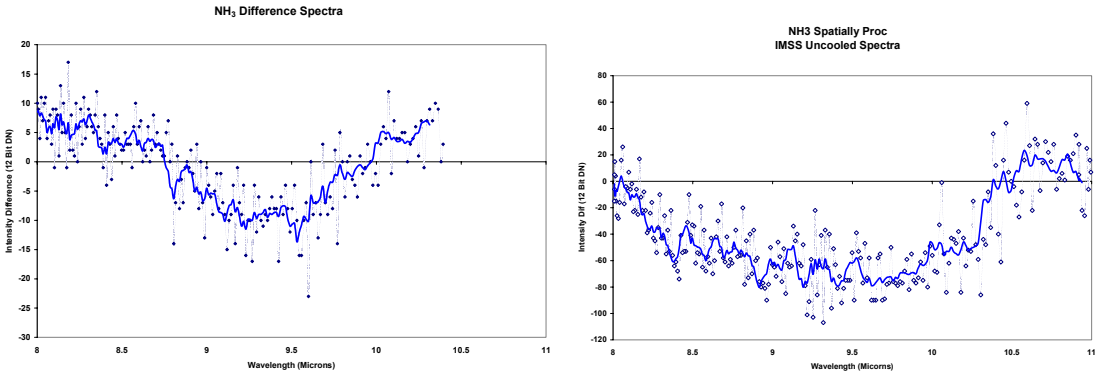

Figure 23. NH_3 spectra as measured with the cooled IMSS system on the left and the uncooled system on the right.

For the two cases where the gas absorption was against a warm (100^o C hot plate) background the spectrum had much better signal to noise. However, there was an uncertainty in the calibration for the cooled system.

4 SUMMARY

This paper has talked about a new technology for hyperspectral imaging, IMSS, which has applications for remote standoff detection of chemical and biological aerosols. This technology has been demonstrated for applications such as gas leak detection for the petrochemical market as well as for remote chemical and biological agent and aerosol detection. There was a cooperative effort between the US Army and the UK MoD in collecting the chemical and biological data to show that passive hyperspectral imaging can be used for standoff detection of these agents. We hope that this work will continue in the future.

More work needs to be done in the area of chemical and biological aerosol agent detection in order to understand the phenomenology and to determine if agent species identification can be made with remote detection using hyperspectral imaging.

Data that was collected at the TRE trials in Dugway in the summer of 2002 for remote standoff detection of biological agents was presented. In addition, data was presented for chemical warfare agent simulants in vapor form were collected during the fall of 2002 at Dstl Porton Down in the UK. A comparison between the cooled and uncooled LWIR IMSS were presented and for most applications it was determined that the uncooled longwave infrared technology does not have the sensitivity to detect the gases at any reasonable standoff ranges.

We would like to acknowledge the support given to this effort from the US Army SBCCOM, and the UK MoD Dstl Porton Down. This joint effort and joint cooperation between the US and the UK is significant in that it will allow the necessary research to enable passive standoff detection for chemical and biological aerosol agent detection to come to fruition in a much more timely fashion than if the two countries were working independently.