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Explosives detection EU FP7 status report 2010

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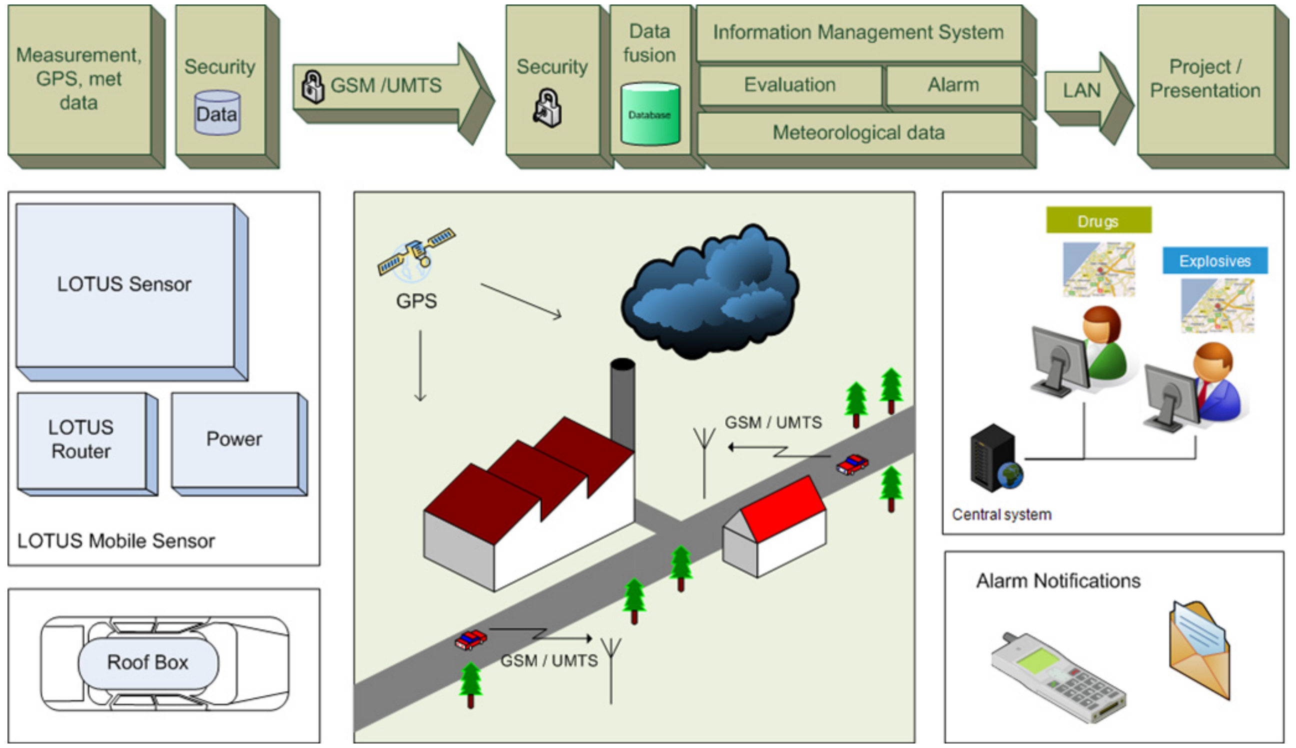

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Explosives detection EU FP7 status report 2010

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Sammanfattning

Genom att möjliggöra FOI:s medverkan i säkerhetsforskningsprogrammet inom EU:s sjunde ramprogram (FP7) ger projektet *Explosivämnesdetektion* Försvarsmakten tillgång till de senaste forsknings- och utvecklingsresultaten inom explosivämnesdetektionsområdet. De FP7-projekt som Försvarsmaktens uppdrag berör är LOTUS, EFFISEC och OPTIX.

Projekten, definierade ur ett civilt perspektiv, studerar frågeställningar som i många avseenden är relevanta för Försvarsmakten. Försvarsmakten får därför hög utdelning i form av teknikutveckling och information. I rapporten redovisas, förutom verksamhet och tekniska resultat, en lista över de rapporter som författats inom projekten. Rapporterna presenteras med titel, ansvarig organisation samt distributionsklassificering.

Inom LOTUS utvecklas ett koncept för att lokalisera bombframställning med hjälp av ett sensornätverk där mobila sensorer monterade på patrullerande bilar kommunicerar fynd av förhöjda nivåer av hotkemikalier till en sambandscentral, ett koncept som även skulle kunna användas i militära insatsområden. Som del av arbetet inom LOTUS har en lista över potentiella HME (home made explosives) och de kemikalier som behövs för framställning av dessa tagits fram. För att utvärdera effektiviteten och för att kunna tolka informationen från de mobila sensorerna har koncentration och spridning av ämnena kring en tillverkningsplats studerats i fältförsök och med teoretiska modeller.

EFFISEC syftar till att förbättra säkerheten vid yttre gränspassager med bibehållet trafikflöde genom att utveckla teknik och verktyg för kontroller. Inom EFFISEC utvecklas detektionsmetoder för CRNE med specifikt fokus på E. FOI utvecklar en punktdetektionsteknik samt en partikelinsamlingsmetod. Känslig och selektiv punktdetektion är generellt tillämpbart i checkpointsituationer med kontroll av personer, fordon eller förpackningar.

I projektet OPTIX försöker man lösa uppgiften med säker avståndsdetektion genom att kombinera tre olika avståndsdetektionstekniker till ett system; Ramanspektroskopi, LIBS (Laser Induced Breakdown Spectroscopy), och laserfragmentering – IR absorption. OPTIX utvecklar en prototyp som kommer att demonstreras i ett avståndsdetektionsscenario där spårmängder av explosivämnen identifieras på 20 meters avstånd.

Utöver att ge stöd åt Försvarsmakten är projektet *Explosivämnesdetektion* nätverksbyggande och ger möjlighet att samverka med andra aktörer i vetenskapliga och tekniska forum. Rapporten ger en kort beskrivning av de ovan nämnda FP7-projekten, samt en beskrivning av 2010 års verksamhet. Annan närliggande verksamhet redovisas också.

Nyckelord: explosivämnesdetektion, HME, Ramanspektroskopi, LIBS

Summary

By enabling FOI to participate in the EU seventh Framework Programme (FP7) Security Research, the project *Explosives detection* provides the Swedish Armed Forces with the latest research and development within the area of explosives detection. The FP7 projects that are concerned are LOTUS, EFFISEC and OPTIX.

These projects have a civilian focus, but the issues covered by the projects are from many aspects in line with the interests of the Armed Forces. The economical means provided by the Armed Forces will thus result in a high yield of gathered information and development of new technologies. The report includes a list of reports generated within the FP7 projects, the reports are presented with title and distribution classification.

Within LOTUS, a concept for localizing clandestine bomb factories within an urban area is being developed. The localization is done using a network of mobile sensors that continuously communicates findings of increased levels of threat chemicals to a control centre, specifying the type of chemical, the time and the location for the finding. This concept could also be used in areas of military operations. As part of the work performed within LOTUS, a list of potential HMEs (home made explosives) and the chemicals necessary for their production has been generated. To evaluate the efficiency of the sensors and to facilitate the interpretation of sensor data, the spread of chemicals/explosives/precursors around a production site has been studied in the field. Other partners have developed theoretical models for the spread of these volatiles.

EFFISEC will provide personnel at the outer border checkpoints of the European Union with technological tools to increase the security at border checkpoints while keeping a high throughput of people. Within EFFISEC, technologies for CRNE detection are being developed, keeping a focus on explosives detection. FOI develops mass spectrometry based point detection as well as electrostatic particle concentration. Sensitive and selective point detection is of general interest in all checkpoint situations where there exists a need of controlling people, vehicles or packages.

OPTIX combines three different standoff detection technologies into one system; Raman spectroscopy, LIBS (laser induced breakdown spectroscopy), and laser fragmentation – IR absorption. The prototype developed will be demonstrated in a standoff scenario of sparse explosive remnants on a surface at a distance of 20 m, providing an identification of the explosive present.

Additionally, the project *Explosives detection* gives support to the Armed Forces, acts as a means for creating networks, and facilitates the communication of research activities in both a scientific forum as well as in other contexts.

The report gives a brief description of the FP7-projects mentioned above and their progress in 2010. Some examples of other activities, aimed at communicating research and results, are also included.

Keywords: explosives detection, HME, Raman spectroscopy, LIBS

Innehållsförteckning

1 Introduction

The project ”Explosives Detection” enables FOI to take part in a number of FP7 Security Research projects by providing co-financing, in return, the efforts undertaken within the FP7 projects will result in significant knowledge- and capability increase. The concerned projects are:

OPTIX - developing an integrated standoff detection demonstrator to be operated from 20 m distance, using three different detection technologies.

EFFISEC - dedicated to enhancing the security at European outer borders, including implementing trace- and bulk explosives detection.

LOTUS - developing a distributed, mobile sensor system that on a daily basis can be used to monitor an urban area to find chemical indications of a clandestine bomb factory.

Also included in the report is PREVAIL, instead co-financed by the Swedish Civil Contingency Agency (MSB). PREVAIL sets out to make some common IED (Improvised Explosive Device) precursor chemicals useless for IED production.

Out of these four projects, FOI is coordinating two, LOTUS and PREVAIL. This report gives a brief presentation of the concerned projects, as well as examples of project achievements for the year 2010.

All the above FP7 projects concern development of detection technologies or security of explosives in general. Through the participation in these projects, FOI can develop better explosives detection capabilities – both point and standoff detection, study effects of dispersion around HME (Home Made Explosives) production sites, develop methods to trace the HME production sites, have an impact on restricting the possibility of using everyday household chemicals for HME production, to mention a few capability improvements that are of interest to the Swedish Armed Forces. By having the opportunities to work with these issues, and doing it together with European partners that have complementary competences and capabilities, we increase the expertise of our own research organization, for the benefit of the Armed Forces. Capabilities developed by FOI within these projects can be directly transferred to other projects, targeting specific issues of concern for the Armed Forces.

Terrorists need a bomb factory for preparing home made explosives or building IEDs in the preparation phase of these types of illicit activities. Since the LOTUS system is aimed at early discovery of attacks and has a proactive focus, the LOTUS system can be implemented both for civilian or military use. As long as the GSM and GPS communication systems are accessible in the area of operation it is possible to transfer the LOTUS sensor data to a command centre for evaluation. The communication and evaluation system is independent from the explosive sensor used. Depending on the explosive threats the appropriate sensors should be used and they can be mounted both on mobile military vehicles and at stationary fixed places and be used as static sensors. The advantage of the LOTUS concept is the possibility for narrowing down the search area in order to find an IED manufacturing facility.

OPTIX develops the standoff capability for finding trace remnants of explosives on items of interest, e. g. on the outside of vehicles or bags in a controlled checkpoint situation, applicable also in a military context. The OPTIX system may be used also in the suspected left behind IED situation. Effective IED/explosives detection in this context is likely to be based on multiple technologies. In the case of OPTIX, the technologies all have standoff capabilities but identify the explosives by different approaches – molecular structure, atomic composition, and fragmentation patterns – thus increasing the probability of reliable detection and correct classification of explosives.

Another approach to be applied in a checkpoint context is used in EFFISEC, where explosives, drugs, other illicit materials, and weapons are detected by close contact methods – to be applied in a checkpoint entrance. Detection capabilities developed for this purpose include sensitive and selective explosives trace detection with online particle collection and vaporization, a radiometric camera that will image items hidden under clothing, a luggage X-ray scanner with spectrometric detector - making material identification by luggage X-ray feasible, and an X-ray scanner for cars and small vans to identify hidden items. All detection capabilities will be connected to a central site where vehicle authenticity verification and biometric person identification together with intelligent video surveillance are all integrated. Developing and testing this kind of checkpoint system can have bearing also for future military checkpoint systems, but additionally, some of the developed technologies are very interesting to apply even as stand alone capabilities.

Of importance is also the network that is created with other European experts and users, making it possible to further increase the efforts in these very important research areas, and to better understand what challenges and capability needs that should be addressed in the future.

Through "Explosives Detection", some dissemination and communication activities on the related subjects are also performed. This concerns the detection expert community as well as civilian and military users. The motivation for this is to obtain a strong profile in the international scientific community, facilitating cooperation and additional funding through partnering and common project applications. Also important is to have a dialogue with the Swedish Armed Forces as well as Civilian Authorities on the requirements and potential of detection technologies and security of explosives solutions. Material from the DETEX/CEREX standoff detection demonstration, held at FOI on November 30 2010, is presented in the report. Although not funded by the Explosives detection project, it has bearing on its focus areas. A proceeding from SPIE Defence and Security conference in Orlando, USA, presented in April 2010, is added as an APPENDIX to this report. In fact, through contacts established during the conference, a joint development of a standoff, on site, post blast forensic equipment demonstrator is considered by FOI and ARL (US Army Research Laboratory). This demonstrator, should the project be realised, will be based on the integration of LIBS (Laser Induced Breakdown Spectroscopy) and imaging Raman standoff detection.

2 FP7-projects – description and progress examples.

2.1 LOTUS

2.1.1 LOTUS summary

Terrorist acts committed using Home Made Explosives (HME) pose an increasing threat against our citizens. The use of HME in the 2005 attacks in the London Underground is a frightening example. Our capability to deal with this threat is challenged by the terrorists' capability to easily manufacture explosives from common components.

LOTUS will address the critical issue of detecting bomb (and drug) factories. The concept and objectives of the LOTUS project are to create a system by which illicit production of explosives and drugs can be detected during the preparation and production phase of a terrorist plot.

LOTUS provides intelligence of a sort that is otherwise not available. This intelligence covers a gap where little information is available from other sources. Detection in this phase has advantages compared to detection of the explosives themselves during e.g. the transportation phase.

The LOTUS project main activities are measurement of the dispersion of pre-cursors at production and surveillance system development. The system capability will be demonstrated by adapting existing and emerging sensors for detection of selected precursors, and integrating the sensors in a networked system. By using existing global infrastructures for positioning (GPS) and networking (GSM) the LOTUS system can be used more or less anywhere in the world with small costs for supporting installations and personnel.

The final outcome of the LOTUS project will be a field test and demonstration. The demonstration system will be based on mobile sensors (3-4) mounted in law enforcement vehicles. Findings from the sensors (type and amount of substance, position and time) are automatically sent to an operations centre display unit where data is collected and evaluated for further action.

The LOTUS consortium consists of three research institutes (FOI, TNO, AIT), two industries (SAAB, Bruker), three SMEs (Portendo, Ramem, Bruhn NewTech), the University of Barcelona, and a group of End Users.

2.1.2 LOTUS concept and objectives in short

The concept and objectives of the LOTUS project are to create a system by which illicit production of explosives and drugs can be detected during the production stage. The demonstration system will be based on mobile sensors mounted in law enforcement and/or other vehicles under community control. Findings from the sensors (type and amount of substance, position and time) are sent, independent of the operator, to an operations centre display unit where data is collected and evaluated for further action.

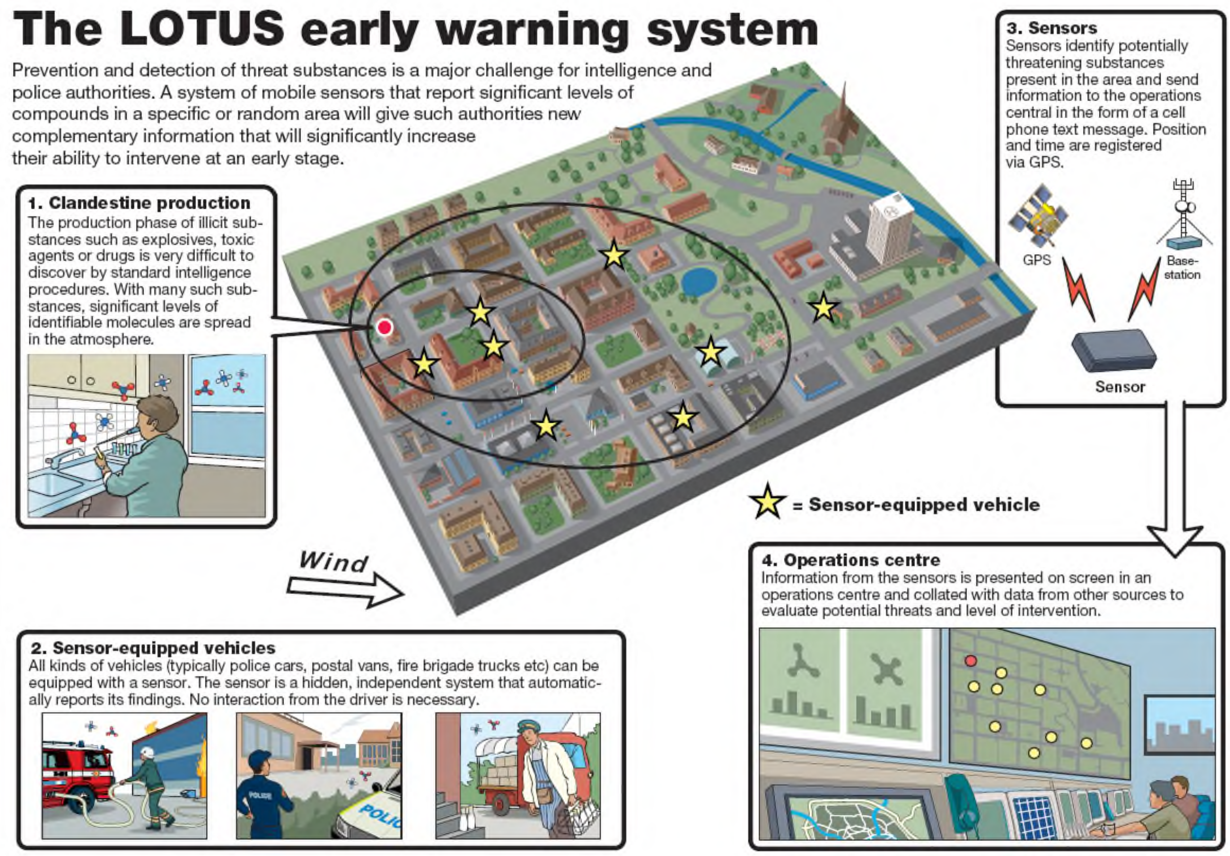

Figure 1: The LOTUS concept

2.1.3 LOTUS project achievements 2010

The partners in the project have been working on dispersion modelling, system integration, sensor development, data transfer encryption and disseminations. Most of the partners have presented the LOTUS results at national, European and international conferences. The project is running according to plan, and 2011 is the final year for the project.

Concentration of diluted hydrogen peroxide, manufacturing of methamphetamine, and drying of explosives after synthesis has been performed on FOI premises. The outdoor releases caused by indoor concentration, manufacturing or synthesis activities (Clandestine laboratory) have been analysed using chemical sampling- and analysis techniques. The weather conditions and amounts of explosives/precursors used have been taken into consideration. Elevated concentrations have been detected at 30 m from the release source for explosives/precursors.

The sensors are now being tested for mobile applications and this system is planned to be ready for use in April 2011. In short, the sensors detect threat substances/backgrounds and these encrypted data are transferred together with GPS data via the GSM network to a server in Europe. A computer based presentation system accesses all this data. The presentation software encompasses data processing algorithms to evaluate the data, and the result is displayed to the operator.

The first trials were carried out during the autumn of 2010 at the FOI premises. A sensor is placed in a standard roof-top box on a car, and air is sampled through an inlet in the box. As the car drives through an area with elevated concentrations of a target substance, an alarm is given, and the position of the alarm is marked on a map.

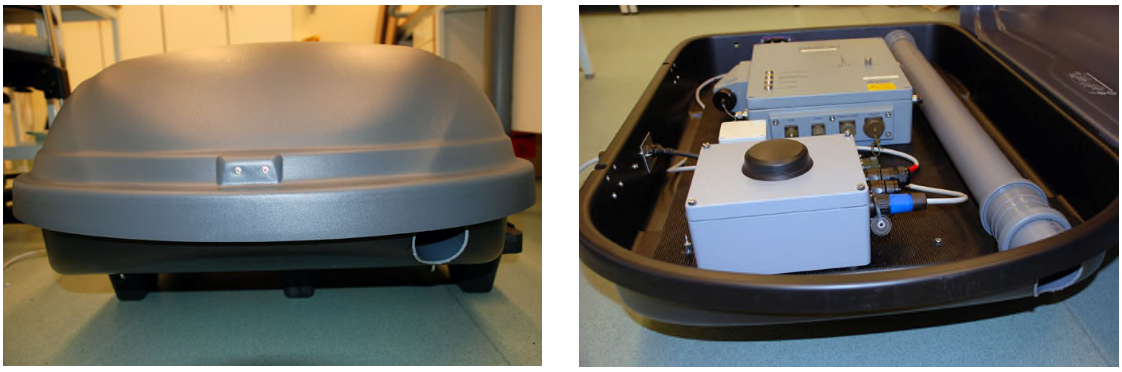

Figure 2:The roof-top box used for the initial LOTUS system trials, exterior and interior.

On December 16th 2010, the entire system, including mobile sensor, data exchange, and presentation software was tested and verified to be functional. The test, carried out at the FOI test site Grindsjön, successfully indicated an emission of precursor substances.

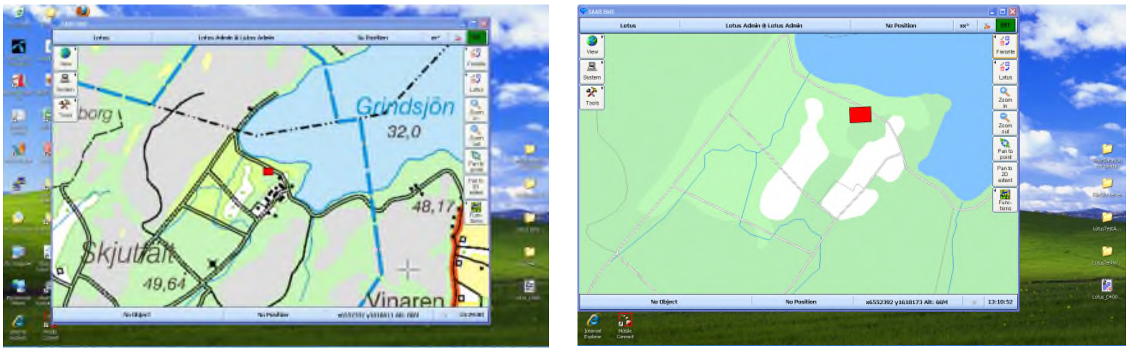

Figure 3: Screen dump from the successful field test carried out at Grindsjön December 16th. Indication of precursor emission is pinpointed to a position near the lake, as marked on the map provided in the software.

In April-June 2011 field trials will be performed with the LOTUS sensors mounted on police cars in at least two European cities. The cities where the field trials will be conducted are at this moment being decided..

The demonstration of LOTUS and the location for this activity is the final part of the LOTUS project and is currently being planned.

2.2 OPTIX

2.2.1 OPTIX summary

Terrorism is a real and growing threat to Europe and throughout the world, more than 60% of the terrorist attacks are carried out by the use of Improvised Explosive Devices (IED). Security forces demand new tools to fight against this threat and the industry has been making a big effort in the last years to provide such tools. New products to detect and identify concealed explosives are reaching the market, but up until now they do not meet the operational capabilities demanded by the users. Probably, the capability most demanded by the users is that off standoff detection and identification of explosives, in order to be able to investigate a threat from a safe distance and to avoid entering into the lethality area of an IED. Standoff detection capability is also needed in intelligence operations to identify materials, people, or places involved in the preparation and transportation of explosives.

In order to meet the end user's needs, OPTIX will develop a transportable system for the standoff detection and identification of explosives in real scenarios at distances of around 20 m (sensor to target), using alternative or simultaneous analysis of three different complementary optical technologies (LIBS, RAMAN, IR) and with the following characteristics:

- Standoff distance of 20 m.
- Detection of explosives in bulk, trace amounts and even liquids under certain conditions.
- Very fast detection and identification of explosives, less than 60 secs.
- Very high specificity for the identification of explosives, 95%.
- Large operational availability of the system: indoor/outdoor, daylight, portability, remote operations.
- Fully automated decision system (no operator dependence).

Laser based technologies provide unique features and capabilities over other potential explosives standoff detection technologies.

In order to be successful, end users involvement in OPTIX is essential in the system specifications and validation, and for this reason, the OPTIX consortium has made a special effort to include end users in those parts of the project where their contribution is relevant.

2.2.2 OPTIX achievements during 2010

The main responsibility of FOI is to lead the efforts in “Technological assessment” and “Test and evaluation of the system”. The first part of this work, “Technological assessment”, was carried out during 2009, and the latter part, “Test and evaluation” is due to start in the midst of 2011,

2.3 EFFISEC

2.3.1 EFFISEC summary

Illegal immigration and illicit material smuggling is a growing concern at the European borders; in that respect border security checkpoints must be particularly efficient against any kind of threat. If airport checkpoints controls are today technically improving. Land and seaport checkpoints differ strongly from airports ones and are more complex to process.

During the last years, most of the efforts were devoted to develop new solutions addressing new security challenges in airports. We can expect that very shortly authorities will have to guarantee the same level of security controls for all types of borders.

The global objective of EFFISEC, a mission oriented project, is to deliver to border authorities more efficient technological tools:

- providing higher security level of identity and luggage control of pedestrians and passengers inside vehicles, at land and maritime checkpoints,

- while maintaining or improving the flow of people crossing borders, and improving work conditions of border inspectors, with more powerful capabilities, less repetitive tasks, and more ergonomic equipment.

EFFISEC will provide border officers with up-to-date technologies:

- allowing systematic in depth controls of travellers, luggage and vehicles, for pedestrians and people inside vehicles, through the use of automatic gates and portable identity check and scanning equipment,
- providing objective criteria for submitting some travellers/vehicles/luggage to an extensive check in specific lanes.

Based on a detailed analysis of the operational requirements (including ergonomics, security and legal issues) for all types of borders, EFFISEC will focus on four technical key issues: documents and identity check, detection of illicit substances, video surveillance and secured communications. The technology proposed will be demonstrated for pedestrians, and travellers using cars and buses; standardisation aspects will be considered and results disseminated.

FOI's main effort lies within SP3 (Sub Project 3), "Illicit material detection", where FOI is SP leader, and also has significant research and development contribution in the form of electrostatic particle collection as well as development of trace detection.

2.3.2 EFFISEC achievements during 2010

Information on the needs of the authorities was gathered during autumn 2009 and spring 2010. This was done both through discussions with the Swedish Police Board and Swedish customs, but also during a visit to the Romanian Border Checkpoint at Albita. This BCP at the Romanian border is one of the locations where the final demonstrations of the EFFISEC solution will be held. In addition, a workshop involving representatives from 19 member states (MS) was conducted at the FRONTEX head quarters (FRONTEX is the European Union agency for outer border security). This was done on initiative from FOI and FRONTEX. At the workshop, a group discussion on explosives detection needs and considerations for border checks was held. One of the conclusions from this discussion was that in order for explosives detection to be performed on a frequent basis, an automated, compact standoff system would be a significant advantage. The checks for explosives could be done without burdening the border officers, thus minimizing the risk that detection will be excluded in favour of other required checks. It would also result in increased safety of border officers in case of an actual explosives finding. The full outcome of the explosives detection discussion group is presented in APPENDIX 1. This information is also integrated in the delivery EFFISEC D1.1-1.

A literature survey was prepared, in collaboration with three of our partners, and delivered to the European Commission, EFFISEC D3.1-1. The survey covers detection technologies, existing and under research and development, ranging from standard analytical techniques, traces detection, bulk detection, imaging techniques and standoff techniques. It also includes an appendix on available R detection technologies. This report will be further updated during 2011, and the aim is to produce a public report on detection technologies before end of 2011.

Additionally, progress has been made on the ESSEX trace detection system. A new TOF-MS (Time of Flight Mass Spectrometer) has been purchased. This system is compact enough to be used at field demonstrations in Romania and Portugal at the end of the project. The system, which uses SPI (Single Photon Ionization) as ionization method, has been assembled and initial testing is planned for early 2011. Equipped with a discrete dynode detector, the system is expected to be more sensitive than the previously used TOF-MS.

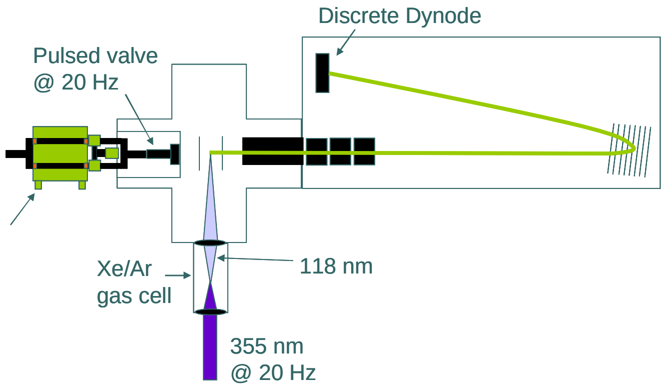

Figure 4: Sketch showing the principle of the SPI-MS instrument that will be used in the final demonstration. The vapour sample is introduced through the pulsed valve, creating a jet of sample air within the ionization chamber. Ionization is achieved using 118 nm photons (deep UV) focussed in the sample jet. The ions are accelerated into the flight tube, and impinge on the dynode detector after a period of time that relates to their respective weight.

The old TOF-MS, which is a lab instrument not suited for transportation, will from now on be available for jet-REMPI ionization experiments. Jet-REMPI will be evaluated as a highly selective and sensitive verification means for laser ionization based mass spectrometry. This ionization technique may in the future be applicable as a complement to the ESSEX SPI-MS system.

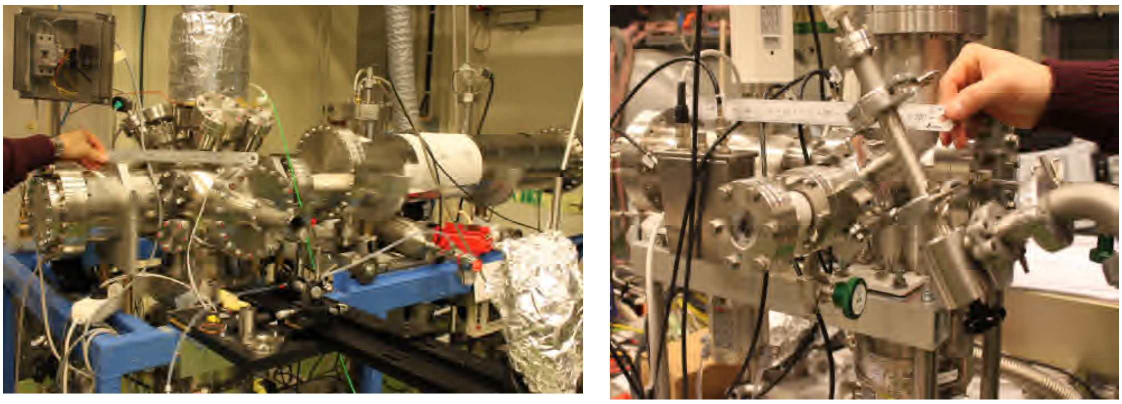

Figure 5: Comparison of old TOF-MS (to the left) and new TOF-MS (to the right). A ruler is placed on top of the systems for size comparison.

Progress has also been made on the development of a particle concentrator. The particle concentrator will be coupled to the SPI-MS (Single Photon Ionization – Mass Spectrometer) system, and will facilitate collection and vaporization of particulate explosives residues, thus making trace detection also of explosives of low volatility possible. The functionality of the particle concentrator has been qualitatively verified. The system is now also equipped with a collection hose to allow sampling of particles from the trunk of a car via a “vacuuming”-process. The details of the particle concentrator are still disseminated only on a restricted level awaiting the finalization of a patent application.

2.4 PREVAIL

2.4.1 Summary of PREVAIL

Home made explosives are easy to make from readily available materials used for legitimate purposes in everyday life. This availability attracts terrorists and criminals to manufacture and use home made explosives since military and commercial explosives are harder to come by. Some of the most important substances when constructing a home made bomb are hydrogen peroxide (HP), ammonium nitrate (AN) and acetone. Because of this, the availability of these chemicals for legitimate purposes poses a great security problem to society today.

There are basically three different approaches to increase the security related to these materials; 1) limiting their availability, 2) tracking their use or 3) limiting their usefulness as explosives or explosives precursors. This third approach is the way forward and the goal for the PREVAIL project.

The PREVAIL project focus on finding inhibitors to 1) prevent the concentration of hydrogen peroxide and 2) prevent production of TATP from acetone. Another project goal is to find a marker/detection system to ammonium nitrate based fertilisers to facilitate detection of illegal use. These objectives must be met without obstruction the legitimate use of HP, acetone or AN, and without causing any adverse effects on the environment or people's health.

Since this project will strongly influence manufacturers of HP, AN, and acetones, users, legislators and governmental security agencies, the ties between the project and the stakeholders are strong. The industrial partners will identify if added inhibitors and markers need extra testing for safety.

2.4.2 PREVAIL achievements during 2010

The project started with a kick off meeting at the Grindsjön research centre (1st September 2010). All partners were represented and all WP leaders gave short presentations of the planned work.

The official website (Milestone 1) is up and running and can be found on www.foi.se/prevail .

2.5 DETEX/CEREX demonstration

On November 30th, a demonstration event took place at FOI, Grindsjön Research Centre. This demo day covered the two different Raman based standoff trace detection techniques currently being developed. Visitors representing the armed forces and support organisations as well as a number of civilian authorities were present. The day started with presentations on DETEX, covering standoff detection of bulk amounts at longer distances – 200-500 m, including measurement through the window of an improvised bomb factory. DETEX has also done work on resonance Raman (RRS), showing that it is possible to do Raman measurements of compounds present only in vapour phase – a capability of importance when targeting detection of the more volatile explosives, pre-cursors and taggants. This fact was also demonstrated live during this day, using lab equipment placed indoors but measuring on gas phase samples of nitromethane (NM) and mononitrotoluene (MNT) placed outdoors. The autumn of 2010 was cold, and day temperature was -8°C. The samples were somewhat heated to facilitate vapour production under these temperature conditions. The NM was a pure liquid, while the MNT was in its crystalline form and mixed with KCl salt, the proportion was 4 % of MNT in the KCl salt. A cloth was placed over the tray with the KCl/MNT mix, to simulate a package. Data processing developed within DETEX was also applied in the demo situation.

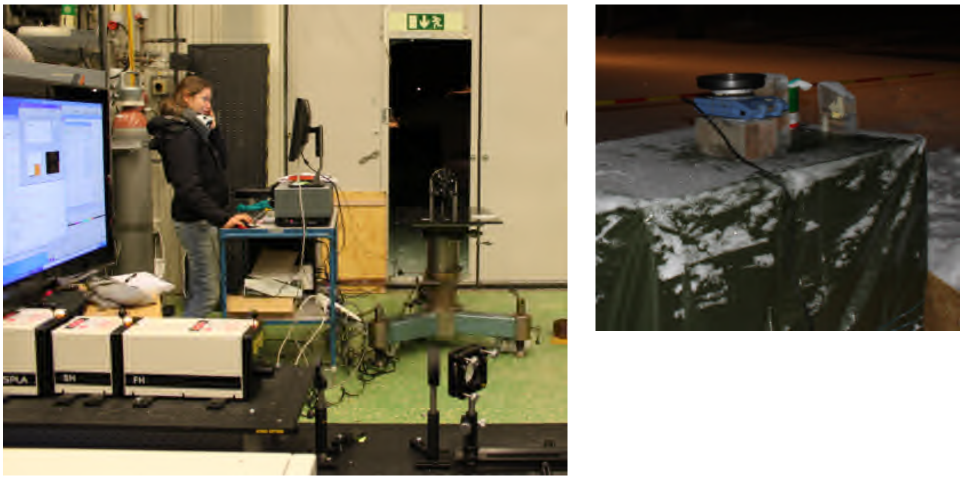

Figure 6: RRS demo at Grindsjön. Either an OPO or a YAG-laser is used, depending on required laser wavelength for the RRS measurements on NM and MNT. The sample is placed outdoors at 10 m distance from the laser and telescope of the RRS setup.

Also demonstrated live was fluorescence suppression using a ps (pico second) laser instead of a ns (nanosecond) laser. Although the detector used was one and the same in both cases, and was matched to ns measuring systems, a significant suppression of fluorescence was demonstrated on a sample of C4. This effect will be pronounced if a matching detector with shorter and sharper gating features is used. Such a result is interesting when considering Raman based detection techniques, since fluorescence, when present, often is so intense that the Raman signal is suppressed to a point where it can not be readily detected. By applying fluorescence suppression in Raman measurements, trace amounts of fluorescing explosives formulations or trace amounts of explosives found on fluorescing surfaces can be successfully detected.

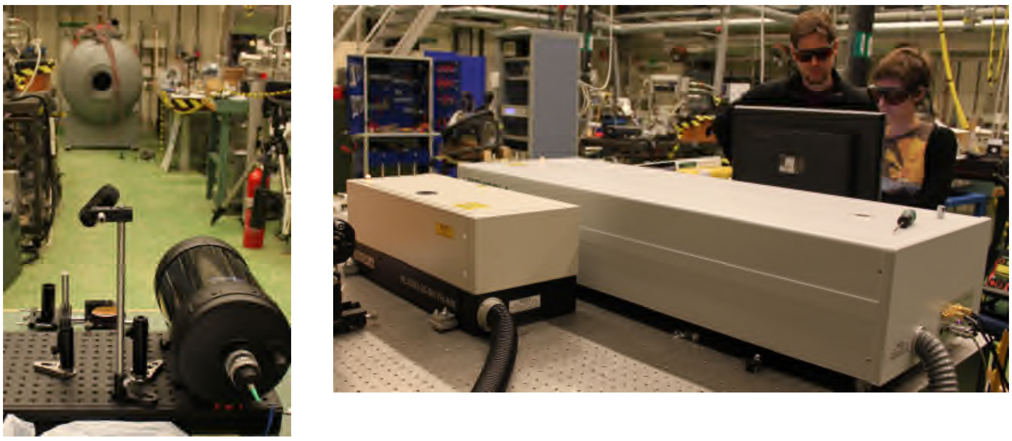

Figure 7: ps fluorescence suppression was demonstrated on the demo day. A sample of C4 is placed in the explosives tank (ssen in left image), and two different laser systems (right image), ns and ps, are used for acquiring Raman data from the fluorescing C4 sample.

On the afternoon of the demo day, the CEREX project was presented. CEREX develops a Raman standoff imaging system that can resolve particles in sizes of 50 µm at 15 meters distance. A lab demonstration was given, where residues of some explosives was identified at 10 meters distance. The laser beam and Raman signal both passed through a Plexiglas window and a car window during measurements. Imaging Raman provides a colour coded image of the residues found on the illuminated surface, providing information on type of explosive encountered. By developing this capability, standoff detection of sparse particle residues left on surfaces by transfer after handling of explosives can be detected. One scenario to consider is standoff detection at a checkpoint, targeting particle residues on the outside of a car, or even inside if line of sight is obtained, e. g. on the gear shift or the steering wheel. Indeed, this capability is now further developed in a Research and Technology transfer project called IED Logistics, starting in 2011.

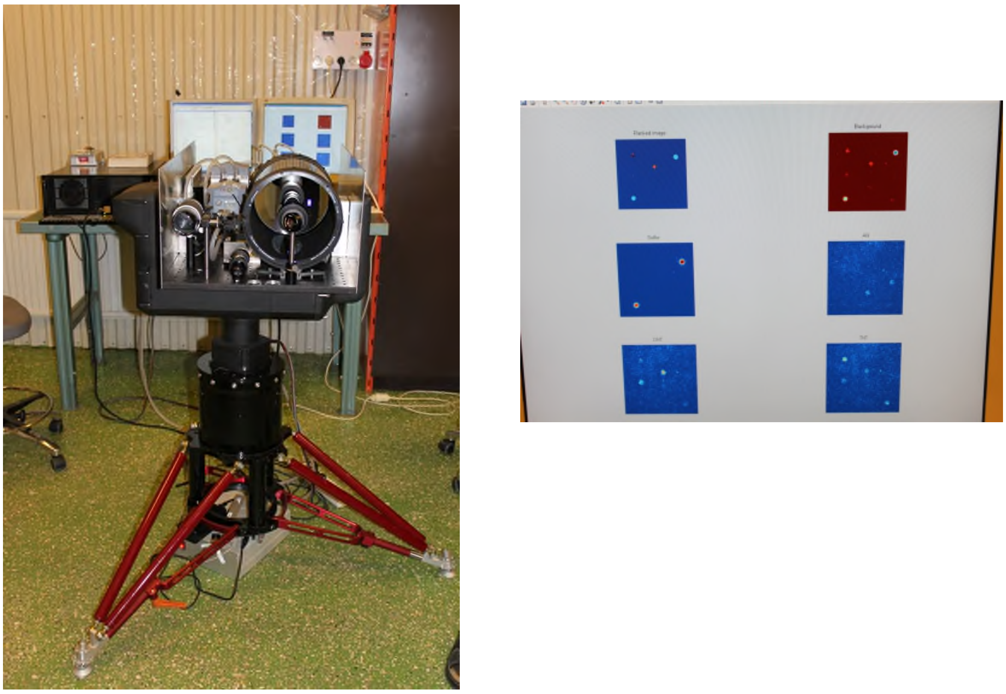

Figure 8: The Imaging Raman prototype (left) and a color coded image of residues of ammonium nitrate, DNT, TNT and sulphur.

The day ended with discussions on possible future applications of the described techniques, some of which will be further developed through upcoming FP7-projects (e. g. EMPHASIS, which essentially will be a continuation of the LOTUS system, targeting a more exact pinpointing of IED manufacturing facilities).

3 Lists of deliveries within LOTUS, EFFISEC and OPTIX

3.1 LOTUS deliverable list

Del no	Deliverable name	Lead participant	Dissemination level[1]
100.1a	Appendices to Report from End User Workshop	FOI	CL Restricted
100.1b	Appendix to Report from End User Workshop	FOI	CL Confidential
100.2a	Threat substance identification, user requirement specification and prel. Dispersion measurements	FOI	CL Restricted
100.2b	Appendix to Threat substance identification, user requirement specification and prel. Dispersion measurements	FOI	CL Confidential
100.3a	Dispersion measurements	FOI	CL Confidential
100.3b	Dispersion modelling	TNO	CL Restricted
400.2	Information analysis	BNT	CO
400.3	Information Analysis Software	BNT	CO
100.4	Scenario requirements specification	FOI	CL Restricted
200.4	System security software 1.0	AIT	PU
700.11	Activity Report	FOI	PP

[1] **PU** = Public

PP = Restricted to other programme participants (including the Commission Services).

RE = Restricted to a group specified by the consortium (including the Commission Services).

CO = Confidential, only for members of the consortium (including the Commission Services).

CL restricted = Classified with the mention of the classification level restricted "Restreint UE"

CL confidential = Classified with the mention of the classification level confidential "Confidentiel UE"

CL secret = Classified with the mention of the classification level secret "Secret UE"

3.2 EFFISEC deliverable list

EFFISEC is an integration project, thus the deliveries listed below are in many cases based on reports issued on a lower level of project hierarchy – thus further information may be available in project internal reports.

Del no	Deliverable name	Lead participant	Dissemination level[2]
1.1-1	Needs of check point authorities, operators and customers	VTT	RE
3.1-1	Survey report on CBRNE detection	FOI	CO
4.1-1	Video-analysis specifications vehicle & passenger's classifications video analytics and behaviour analysis	Elsag Datamat	CO
5.1-1	Architecture of the complete system	Selex Galileo	CO
6.2-1	EFFISEC web portal	University of Reading	PU
6.2-2	Internal guideline for co-operative work	University of Reading	CO

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3.3 OPTIX deliverable list

Del no	Deliverable name	Lead participant	Dissemination level[3]
1.1	WP1 initial report including: - Report on literature search on technology status for LIBS, Raman and IR - Report on the applicability of the core technologies to the detection and identification of explosives and assessment of integration of the technologies	FOI	RE
2.1	Workshop with end users: Report on the selected scenarios and other result of the Workshop.	Guardia Civil	PP
9.1	Web site and project presentation	INDRA	PU
10.1	Management Hand book	INDRA	PU
10.2	Project Quality Plan	INDRA	PU
2.2	System requirements specification and system and subsystem preliminary design	Univerity of Malaga	RE
3.1	Specification and design of LIBS subsystem including: - Spectral library of explosives for LIBS based detection and identification of explosives - Specification and Design of the LIBS based prototype	Technical University of ViennaN	RE

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Del no	Deliverable name	Lead participant	Dissemination level[3]
4.1	Specification and design of RAMAN subsystem including: - Spectral library of Raman spectra of explosives and related material - Specification and Design of the RAMAN based prototype	Technical University of Clausthal	RE
5.1	Specification and design of IR subsystem including: - Spectral library of fragmentation products for selected explosives - Specification and Design of the IR based prototype	EKSPLA	RE
6.1	Study and Design of: - 3 source OPTIX laser source prototype. - ultra sentive OPTIX spectrometer prototype. - optical sub assemblies - Set of well documented analysis methods (chemometrics)	INDRA	RE
9.2	Detailed dissemination plan. M-14 version	INDRA	PU

4 SUMMARY

The projects LOTUS, EFFISEC and OPTIX have been briefly described, including the progress in 2010. A list of deliverables is included in the report – this list may serve as a means for selecting areas for more detailed information communication. This can be done taking into consideration the project and security classifications of the reports of interest.

Some additional information has also been included in the report, such as an overview of the FP7 project PREVAIL, covering an area that is indeed relevant for fighting the problem of HME production – by chemically inhibiting and preventing the production of HME's.

Other material included encompasses a conference paper on explosives standoff detection presented in SPIE, Orlando 2010, a reference of the demo day held at FOI premises in November 2010 related to the same subject, and notes from a FRONTEX workshop on the subject of outer border checkpoint security.

APPENDIX 1 - FRONTEX workshop discussion on illicit material detection

The discussion was started with a brief description of the EFFISEC suggested illicit substances detection solution, presented in a vehicle check case. According to this, vehicles that come to a halt for checking of identity documentation and biometrics will also be subject of screening for hidden illicit materials. This will be done using near real time trace detection capability. Here is also an opportunity for gamma radiation detection. All vehicles that are picked out for a more thorough check, based on any indication from border officers or technological equipment, are directed to a second lane where a more thorough search can be conducted using bulk detection techniques. X-ray of the full vehicle and the luggage can be performed, and there is an option of a radiometric camera. This thorough check will require more time..

The presented scenario led to some discussions on the situation today, and what properties must be respected for such a detection solution to be implemented. It was clear that the time available for the initial screening is very short, in the order of 20 seconds, and during peaks in flow over the day perhaps even shorter that that. As was anticipated, the time for a secondary check is more relaxed.

For an initial screening to be advantageous, it must be fast, but it should also be sensitive to multiple substances. There is obviously a wish for sensitive as well as selective detection capability with low positive and negative alarm rate. Such a solution could also be applied in other situations than the border checkpoint, e. g. mail rooms.

The operators would want a single engagement with the vehicle, why the illicit substances screening should be performed simultaneously with the identity check.

The delegates stressed that a problem today is the lack of personnel and the lack of space, indicating that at this point, a checkpoint solution that would require additional personnel in order to operate new instrumentation, or that would require additional space for placing of the instrumentation, would be problematic. This is true from both a first and second line check perspective.

In fact, it was concluded that a future solution for illicit substances screening (first check) should be non invasive, automated, and unmanned, meaning that an automated standoff solution would be desirable. This would solve the problem of having to acquire more personnel, as well as minimizing the security risks for the border staff.

X-ray is already in use today, but since it is time consuming to perform, it is only used in targeted first line check. Again, a secondary check is more time relaxed. To invest in new instrumentation, there is however a need for significantly improved capability. In example, an increased resolution that would enable detection of illicit substances in amounts one order of magnitude smaller than today. Enhanced material identification capability could also be interesting.

At the end of the discussion, future demands (of illicit substances detection) were discussed and summarized. Some of them were already mentioned above, but are included in the bulleted list below.

Future demands:

- More automatic/less contact (need for less personnel)
- Standoff
- Important to protect border officers (explosives, CBRN)
- Space effective control

This was commented above. Lack of personnel and space is a problem already, and anticipated future increase in flow over borders will not improve this situation. Automated standoff detection would be a solution that would also be effective in protecting border officers from explosives and CBRN

- Multiple substance capability
- Low number of false alarm/no miss of alarms

The versatility of the detection solution is important. In order for the detection solution to be effective, there are significant demands regarding both selectivity and sensitivity

- Anti spoofing (no way to conceal)
- Scanners for consumed drugs
- Fast and reliable -and cost effective- scanning of the human body's interior would be a desirable future capability. Perhaps there are other solutions to this problem as well, based on fast trace analysis?
- Part of full system (profiling/analysis etc)

It was clear from the presentations from numerous delegates earlier in the day that the combination of methodologies is a winning concept. The experienced border officers as well as efficient instrumentation are both important in the process, the use of profiling and risk analysis is a well proven concept. Most effective outcome of any new capability or instrumentation is for it to be integrated with other means of performing checks.

- Need improved technology for fast, accurate hidden person detection

The hidden person detection is not addressed within the EFFISEC concept, it was however discussed frequently during the workshop. Reliable and fast hidden person detection is obviously a needed capability for border police officers today. In use today are typically CO_2-detectors, heartbeat detectors and sniffer dogs.

- Detection of mixed/solved illicit materials (e. g. drugs in scotch)

A solution for this kind of problem is sought both for explosives detection, to be applied at security checkpoints at airports for instance, but also has its application for finding drugs.

- Instrumentation need to be practical to employ (not slow, bulky, expensive, non-accurate)

An obvious demand with perhaps a not so obvious solution

APPENDIX II – SPIE conference proceedings, Orlando, Florida 2010

On following pages…

EXPLOSIVES STANDOFF DETECTION USING RAMAN SPECTROSCOPY: FROM BULK TOWARDS TRACE DETECTION

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ABSTRACT

This paper gives a brief overview on our latest progress in the area of standoff detection. Standoff Raman measurements from 200 m and 470 m distance have been performed on bulk amounts of TATP and AN respectively, the former through a double sided window, the latter under heavy rain. Resonance Raman measurements on TNT, DNT and NM vapors in the ppm concentration regime are presented, showing resonance enhancement in the range of 2 200 (NM) to 57 000 (TNT) as compared to 532 nm Raman cross sections. Finally, the application of hyper spectral Raman imaging is described, exemplified by the resolution of four different samples (sulphur, AN, DNT, and TNT) in the form of 5 mm wide discs in one single image.

Keywords: Raman, spectroscopy, RRS, resonance enhanced, explosives, IED, imaging, vapors, standoff, detection

INTRODUCTION

In an international perspective, there are currently much research activities concerning explosives detection, and standoff detection of explosives is in main focus. The reason for this interest is the occurrence of terrorist attacks on the civilian society involving improvised explosives devices (IED's), such as the bombings in London underground in July 2005 and the Madrid train bombing in March 2004, but also the situation that armed forces will encounter on international missions, where IED's are used against military personnel as well as civilians.

The goal for standoff explosives detection is to achieve means for fast and selective identification of an IED, or the explosives to be used in an IED, at a distance that will keep all personnel and equipment outside the zone of severe damage in case of a detonation of the device.

When targeting detection of the actual explosive material, the method should preferably be molecular specific. Requirements regarding sensitivity are also considerable, since many explosives are of low vapor pressure (the vapor pressure of TNT (an explosive in the mid vapor pressure range) is $4.2\cdot10^{-4}$ Pa @ 25 °C (~$3.2\cdot10^{-6}$ torr) [1]), and typically contained in some way. Because of the need for specificity, sensitivity, and standoff capability, there are many laser spectroscopy methods being considered for this application. Examples of such methods are LIBS, photofragmentation combined with LIF (PF-LIF), Raman, Resonance Raman,

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CARS, THz spectroscopy, resonance thermal imaging and more. A recent review by Wallin et al [2] gives more details about the techniques being developed for explosives standoff detection.

The standoff explosives detection work done at FOI has been focussed on Raman and Resonance Raman spectroscopy which is quite easily performed also at standoff distances. The interest in Raman spectroscopy for standoff explosives detection is shared by other research groups, and there are a number of recent publications on bulk detection using Raman spectroscopy [3-6]. One issue that has been in focus is the problem of fluorescence – both from the background but also from the explosive itself. To overcome this problem, it has been suggested to use shorter wavelengths (preferably below 250 nm) [6, 7], or to use ps laser systems and temporal filtering [8, 9]. There is also an interest in using resonance enhanced Raman spectroscopy (RRS) for explosives detection, and work performed on explosives in solid form [10] or in solvents [11] have recently been published.

This paper describes briefly some of the work on Raman based explosives standoff detection that is being performed at FOI. Bulk detection of explosives and related compounds has been achieved at distances up to 470 meters under varying weather conditions, and through windows at distances of 200 meters. The possibility to identify explosives at 55 meters distance under different weather conditions and through transparent container materials has been described in a previous paper [12] and as a continuation of this work the distance has now been increased to point out the flexibility and applicability of spontaneous Raman spectroscopy.

The applicability of standoff detection would much benefit from trace detection capability. Such capability would render possible to identify an IED from sparse particulates on the outside of a package, or from vapors around the explosive containing object. To approach these very challenging demands, we have chosen to direct our efforts towards RRS for vapor detection and towards imaging Raman spectroscopy for particle detection. This paper also describes briefly the recent efforts in both these areas.

EXPERIMENTAL

All three presented varieties of Raman spectroscopy share some enabling instrumentation. The use of a pulsed laser source combined with gated, sensitive ICCD detection suppresses ambient background efficiently, making the environment in which measurements are performed of less importance. To achieve resonance enhancement, a UV tuneable laser source is necessary. For spontaneous Raman spectroscopy, a Q-switched, frequency doubled YAG-laser emitting green laser light (532 nm) works well in many situations, having good transmission through air, moisture, and materials appearing transparent to the eye.

If possible, signal to noise ratio benefits from using a filter to block the laser line scattering, e. g. a sharp edge, long pass filter. This is straightforward when using a standard laser source such as a Nd:YAG, but more difficult for a tuneable laser system. Distinct edge filters could often be chosen also for this application.

The Raman signal is effectively collected by means of a telescope. In these experiments, standard amateur astronomer's Schmidt-Cassegrain telescopes are used for detection in the visible wavelength region, while the UV measurements put additional constraints upon choice of telescope. A reflectance based UV telescope of Cassegrain type was used for the RRS measurements.

For longer standoff distances – in the order of hundreds of meters, the use of a beam expander will help reduce divergence of the laser beam. The 200 m and 470 m measurements were performed using a 1:5 beam expander.

In standard configuration, the telescope is coupled to a spectrometer via an optical fibre. For the imaging measurements, direct coupling between the telescope and an ICCD detector is used. Signal wavelength selectivity is achieved by means of a tuneable filter placed in between telescope and ICCD. By placing a beamsplitter in the optical path, a white light image can be displayed/recorded by a digital camera while Raman spectra are being acquired.

Standoff bulk detection

The main components for the long range Raman measurements are the following: A pulsed, frequency doubled Nd:YAG laser generating 4 ns long laser pulses at 532 nm and pulse energy of 320 mJ, a telescope to collect the signal from standoff distances, coupling of the signal between the telescope and a spectrometer via optical fibre and coupling optics, including a long pass filter to suppress the laser wavelength, and a spectrometer with mounted ICCD detector – using detector gating matching the laser pulse length will suppress ambient background. Figure 1 gives the schematic of the Raman standoff experimental setup used for bulk measurements.

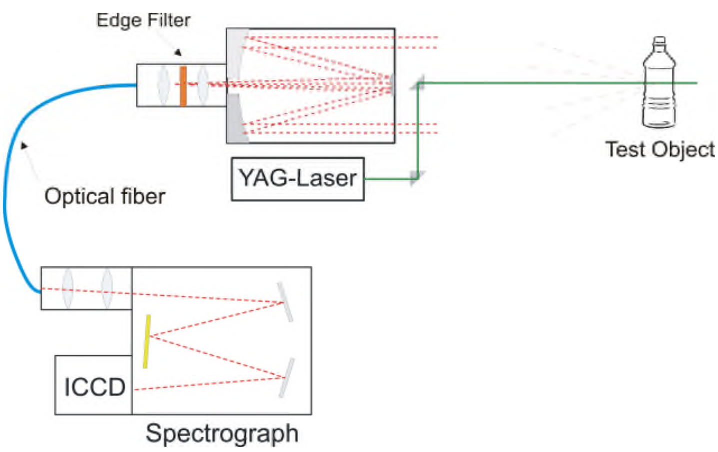

Figure 1: Experimental setup used for standoff Raman detection of explosives. Distance from instrumentation to object is either 200 m or 470 m in the presented measurements. Measurements were sometimes made in an oblique configuration instead, using a anti reflection coated mirror placed close to the telescope to direct the laser beam onto the sample.

Long range standoff measurements were performed on different occasions. The 470 m measurements were performed across a lake, with the emitting and collecting components placed on one side and the sample on the other. During one occasion, heavy rainfall set on, and the opportunity to test long range detection under such circumstances was taken. These measurements were performed on bulk amount samples, for nitromethane (NM) a 1000 ml glass container, for ammonium nitrate (AN) a 500 ml glass container, in both cases partly filled with the sample substance. No attempts to find a detection limit was made, instead the purpose was to test the viability of standoff Raman measurements at these distances. The 200 m measurement was performed through a double sided window, targeting a bench inside a small barrack where 2 g of TATP was placed. This configuration allowed for optical access to the TATP from the position where the instrumentation was placed.

RRS measurements

The experimental setup for RRS measurements is in many ways similar to the spontaneous Raman setup. The main difference lies in the laser source, which in RRS measurements need to be tuneable within the UV wavelength region, but also the requirements on optical components that stems from the use of UV wavelengths. For instance, a reflection based coupling system is preferred. A Nd:YAG pumped OPO (Optical Parametric Oscillator) was used as laser source for all RRS measurements.

The OPO is custom built to be tuneable in the wavelength range 195-2300 nm. It has a pulse length of 6 ns, a repetition rate of 10 Hz, and a beam diameter varying with wavelength from 5-8 mm. Depending on operating wavelength the pulse energy varies between 3 and 10 mJ. The use of a tuneable laser source allows for tuning the laser wavelengths so that it approaches an existing electronic transition of the target substance, thus resulting in resonance enhancement of the Raman signal. A schematic of the setup used for the lab based measurements can be seen in Figure 2.

So far, most measurements have been made in the laboratory, at close range, to establish basic parameters of resonance enhancement for a number of substances. To control experimental parameters, a temperature and pressure controlled chamber was used, and concentration of explosives vapor was derived from data on the vapor pressure's dependence on temperature. The setup was designed primarily to allow for Raman cross section determination, and not for optimal sensitivity. Presented here are measurements on TNT and NM. Additionally, the results from the DNT measurements are listed in the table on the experimentally derived resonance enhanced Raman cross sections. The chamber was filled to ambient pressure using nitrogen gas, which is then used as an internal standard when determining experimental resonance enhancement of Raman cross sections.

A standoff measurement from 13 meters is also presented - in this case, the laser beam and telescope were directed outdoors onto an open container NM sample placed in the outdoors, and measurements were performed in the vapor above the sample. Vapors were fully exposed to the open air (no containment of vapors).

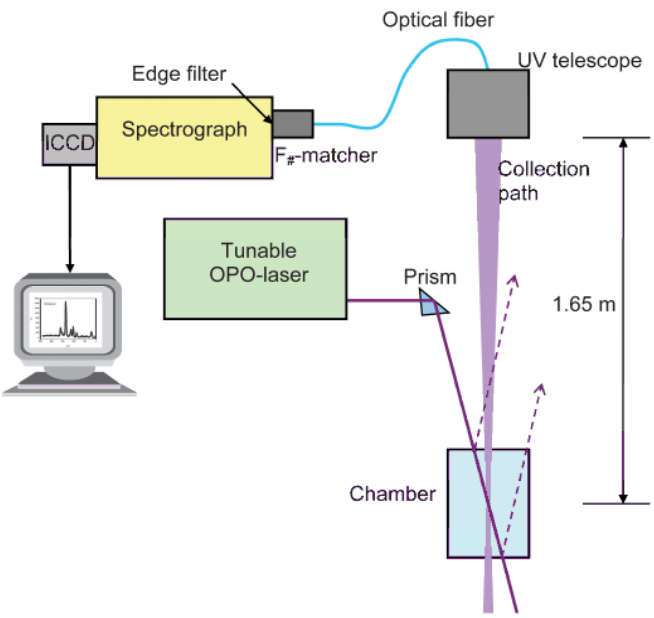

Figure 2: RRS experimental setup used for resonance enhancement characterisation. Chamber is temperature and pressure controlled. Measurements are done on vapors.

Imaging Raman spectroscopy

Instead of a wavelength dispersing spectrometer, a LCTF (liquid crystal tuneable filter) is used. Tuning range for the filter is between 480 nm and 720 nm in steps of 0.01 nm, with a bandpass of 0.25 nm. By inserting a beamsplitter into the optical path before the LCTF, a white light image of the area under investigation can be collected. The laser/spectrometer system is otherwise basically the same as for the long range standoff measurements. A schematic of the experimental setup can be seen in Figure 3.

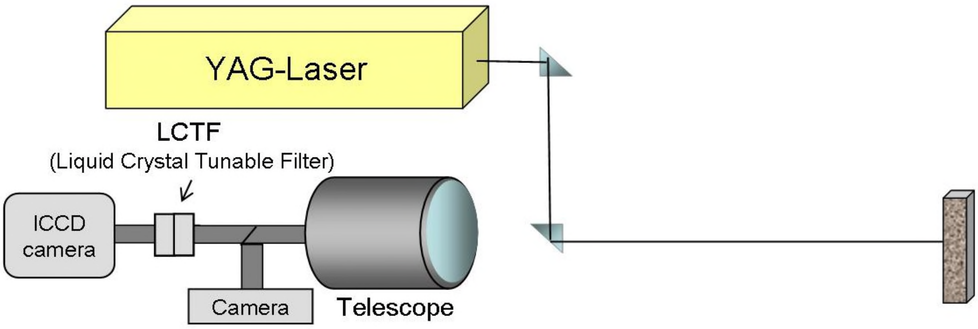

Figure 3: Experimental setup for the imaging Raman experiments. Distance between setup and sample was 10 m.

For the imaging experiments, the measurements were performed indoors, at a distance of 10 m. Four different samples were used, pressed pellets of a diameter of 5 mm, flat surface facing the laser/telescope. The substances used were sulphur, DNT, AN, and TNT, all placed in front of a brick which served as a non-interfering background for the measurements. The LCTF was used to scan a number of selected spectral points of each substance.

RESULTS AND DISCUSSION

Standoff bulk detection

NM and AN were chosen as samples as they can be used as main ingredients of HME's (home made explosives). In Figure 4, a comparison between spectra acquired on a sunny summer day and during heavy rainfall can be seen. Spectral quality is effected by the rain, but AN spectral features are clearly visible for all acquisitions. Acquisitions were of 100 accumulations and 10 accumulations – corresponding to 10 and 1 s measurements – at both occasions.

The decreased S/N ratio for the measurements performed during rainfall is likely to be due to scattering of both laser light and signal on water drops and water aerosols being present in the optical path. The laser beam was partly visible when traversing the lake, clearly supporting this assumption. Measurements on NM and FOX7 high explosive were also performed on the first occasion. Details of all measurements will soon be available [13].

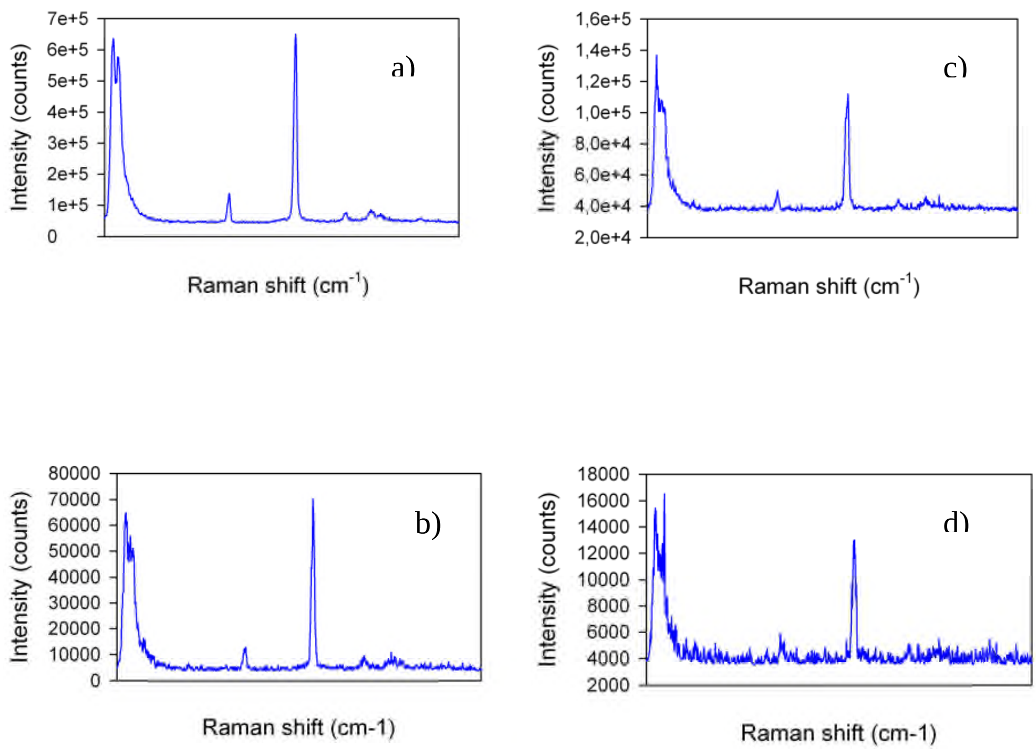

Figure 4: AN spectra acquired on two different occasions at 470 m distance. Details on spectra are as follows; a) accumulation of 100 spectra, acquisition time 10 s, acquired on a sunny day, b) accumulation of 10 spectra, acquisition time 1 s, acquired on a sunny day, c) accumulation of 100 spectra, acquisition time 10 s, acquired during heavy rainfall, d) accumulation of 10 spectra, acquisition time 1 s, acquired during heavy rainfall.

In Figure 5, a spectrum of TATP acquired at 200 m distance can be seen. Acquisition time was 10 s, resulting in a spectrum of 100 accumulations. A picture of the test field can also be seen, with a view from the instrumentation position and towards the little barrack and its double glassed window. Optical access to the sample is obtained through the window onto the TATP sample of 2 g.

Depending on the situation at hand, standoff bulk detection by Raman spectroscopy may be of value because of its ability to identify the investigated substance. Provided that optical access to the sample can be obtained, standoff identification of unknown substances through the windows of a house, car etc., can be achieved with high specificity. The results presented so far have referred to bulk amounts of sample substances, in the amounts of a few grams to hundreds of grams. Measurements performed at 30 m gives at hand that 1 mg of sample (AN, DNT, TNT) can be readily identified. Efforts on developing signal processing algorithms to help evaluate acquired spectra with respect to probability of identification is being done in a collaborative effort [14]. With respect to the low availability of traces from explosives upon handling of an IED, 1 mg should still be considered as bulk amount.

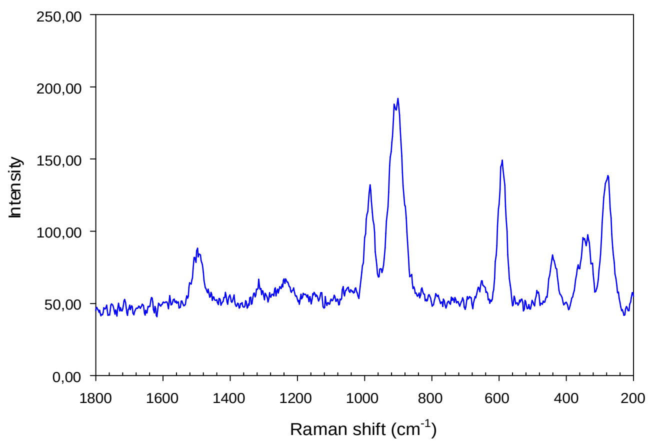

Figure 5: The test field for the 200 m measurement as seen from the instrumentation site. The barrack has a small, double glassed window through which optical access to 2 g TATP is obtained. The spectra is of 100 accumulations, acquired during 10 s, and obtained from 200 m distance through the window.

4.1 RRS measurements

Measurements on nitromethane, DNT and TNT in vapor phase has been performed in order to evaluate the resonant behaviour of these substances, and to investigate the possibility to use resonance Raman spectroscopy for the purpose of standoff detection of explosives in vapor phase.

In the present laboratory study only a small interaction volume was investigated, and the measurements therefore had to be performed at elevated temperatures in order to reach high enough concentrations. However, with a modified setup designed for realistic conditions, where larger interaction volumes will be used, this should not be necessary.

The level of resonance enhancement of Raman cross section is given in comparison to the Raman cross section for the vapors at 532 nm as found in literature. All measurements were made in a nitrogen atmosphere at ambient pressure. Nitrogen is not resonance enhanced in the wavelength regime of interest, and is always present in the acquired spectra; therefore it is useful as a reference for enhancement evaluation. Its cross section is extrapolated from literature data given for the 2331 cm^{-1} N_2 transition at an excitation wavelength of 377 nm [15].

In Figure 6, the resonance Raman spectrum of nitromethane vapor of 24.35 Torr can be seen. The laser wavelength was 323 nm, at which maximum enhancement was reached. The enhancement factor, F_{max}, is found to be 2 200. The occurrence of a second, third and fourth order of the nitromethane double peak at 1374 cm^{-1} and 1394 cm^{-1} could be used to increase the probability of identification when measured in a complex matrix.

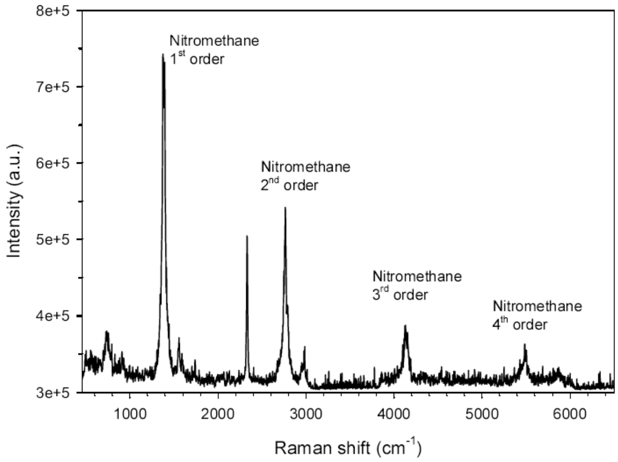

Figure 6: The resonance Raman signal from nitromethane at 232 nm excitation wavelength, at which maximum enhancement was achieved in this experiment. The spectrum shows the first, second, third and fourth order of the Raman signal, and is a combination of two subsequent spectral acquisitions to cover the full 6300 cm^{-1}. The temperature was 291 K, giving a vapor pressure of 24.35 Torr.

Enhancement varies between specific vibrational transitions. For TNT, enhancement was determined for the 1347 cm^{-1} transition, which can be quantified in relation to the 2331 cm^{-1} N_2 transition. A TNT RRS spectrum is shown in Figure 7. Also shown is how the resonance enhancement varies with laser wavelength. Maximum enhancement is found at an incident wavelength of 250 nm, resulting in an enhancement factor F_{max} of 12 800.

The maximum enhancement is found redshifted from the absorption maximum for the respective analyte vapor, an effect most likely originating from absorption and self absorption of the laser light and RRS signal. Indeed, results indicate that a lower vapor concentration is beneficial to enhancement of cross section as is illustrated in Figure 8. This is something that can work in favour for trace detection of explosives, or other chemicals, in vapor phase in real life scenarios. Chemicals which are Raman active and have vapor pressure, such as e. g. chemical warfare agents, can be targeted for vapor RRS detection.

In conclusion, RRS enhancement is found to vary between 2 200 times and 100 000 times for the base data meaurements, with the higher value achieved for the 1353 cm^{-1} peak in DNT. Results are summarized in Table 1. A paper giving detailed information on the base data measurements is under preparation [16].

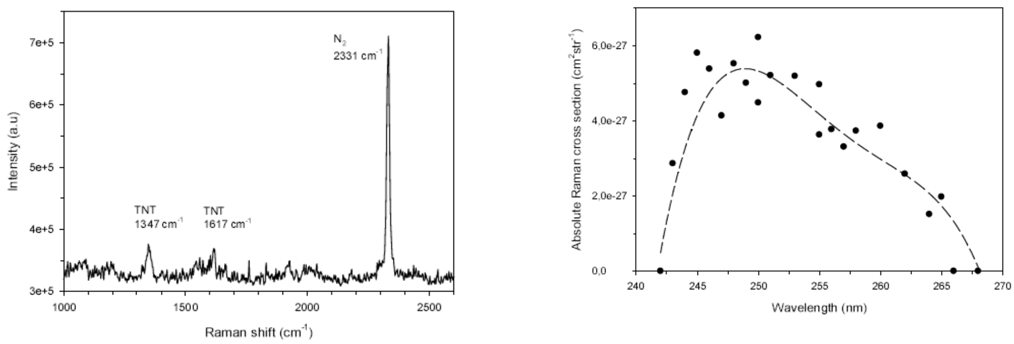

Figure 7: To the left; resonance Raman signal from TNT at an excitation wavelength of 248 nm, using a long-pass filter cutting at 248 nm. The temperature was 401 K (128°C), where the vapor pressure is 0.254 Torr, resulting in a TNT concentration of 341.2 ppm. To the right; The dependence of absolute Raman cross section on incident wavelength for the transition at 1347 cm^{-1} in TNT at 401 K (128° C). The dashed line is intended to guide the eye. The maximum of the cross section is found at an incident wavelength of approximately 250 nm, where the enhancement compared to 532 nm is 12 800. TNT concentration was 341.2 ppm.

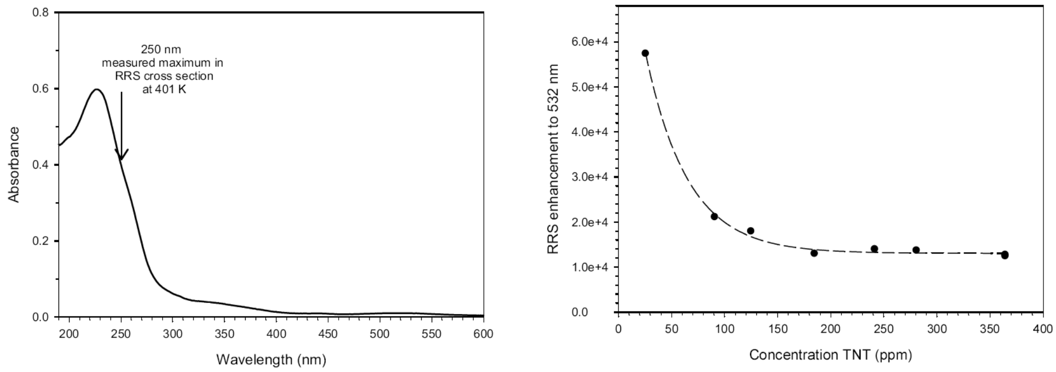

Figure 8: To the left; UV-absorption of TNT 7mg/l in solution with acetonitrile. The arrow shows the wavelength where the maximum in Raman cross section is found in the present vapor phase measurements at 401K. To the right; enhancement of the resonance Raman signal at 1347 cm^{-1} compared to the Raman cross section at 532 nm, at different TNT concentrations. The wavelength of the incident light was 248 nm, close to the maximum in the cross section found for a concentration of 341.2 ppm. Dashed line is an exponential fit to the data points. At a TNT concentration of 26 ppm the enhancement compared to 532 nm is 57 000.

Table 1: Measured maximum enhancements. Here λ_{max} is the incident wavelength resulting in the highest cross section, ω is the Raman wave number of the observed Raman peak, σ is the obtained cross section, and F_{max} is the enhancement factor compared to the cross section at 532 nm.

Substance	λmax (nm)	ω (cm-1)	σ (cm2str-1)	Temp. (°C)	Conc. (ppm)	Fmax
NM	232	1374/1394	8.3×10-28	18	32,500	2,200
2,4-DNT	263	1353	9.8×10-27	110	1,445	20,000
2,4-DNT	~ 260	1353	2.2×10-26	95	432	45,000
2,4-DNT	~ 250	1353	5.1×10-26	81	126	100,000
2,4,6-TNT	250	1347	6.0×10-27	128	341	12,800
2,4,6-TNT	248	1347	2.8×10-26	96	26	57,000

Measurements on NM vapors were also tried in an outdoors scenario – the open container of NM was placed 13 m from the emitting/collecting instrumentation, in an adjacent test field – the instrumentation could in this way be kept indoors. The NM was heated to 328 K (55°C), while the outdoors temperature was 274 K (1°C). The laser beam passed 5 cm above the surface of the NM. The vapor cloud was fully exposed to wind. The optimal laser wavelength for these measurements was found to be 220 nm, as compared to 232 nm for the lab measurements, likely an effect of reduced self absorption. A resulting NM spectrum can be seen in Figure 9.

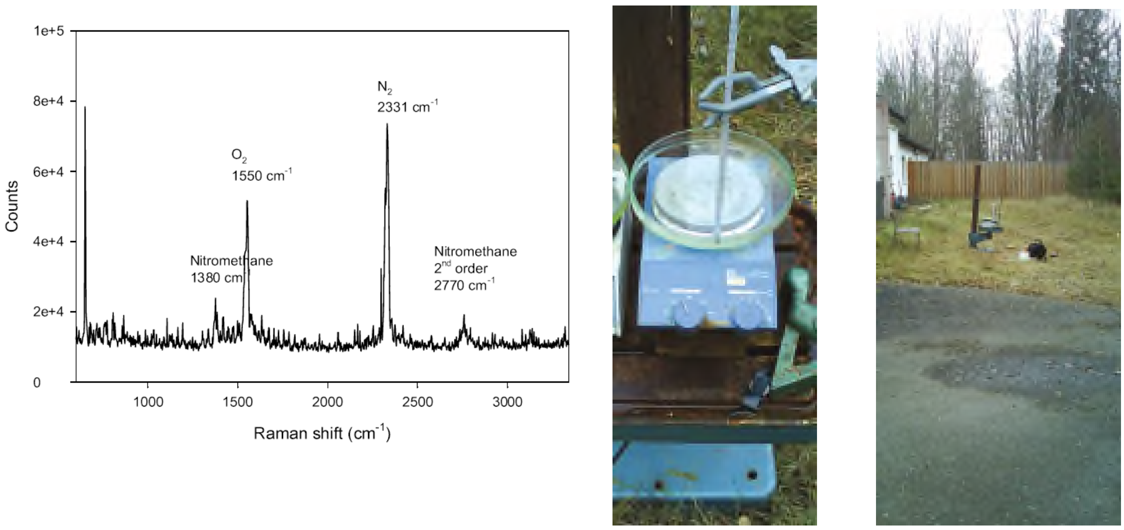

Figure 9: To the left; Resonance Raman signal from outdoor measurement on nitromethane in vapor phase at an irradiation wavelength of 220 nm. The nitromethane temperature was approximately 328 K (55°C) and the outdoor temperature was 274 K. The spectrum is accumulated from 1000 laser pulses, i.e. in 100 seconds. The two images to the right; a close up of the open NM container, and the container as seen from the lab.

Imaging Raman spectroscopy

Figure 10 shows a selected series of wavenumbers corresponding to the peaks and baseline of a TNT Raman spectrum. For the imaging measurements, the LCTF is tuned over the wavelengths matching the selected wavenumbers. For each selected wavelength, a monochrome intensity image is recorded by the ICCD detector. All collected images are then processed using MathLab to form a spectrally resolved image of the surface. In effect, this will create an image where only the particles matching the selected Raman profile(s) will appear. This image can be overlaid with the optical image.

The resulting species specific images can be seen in Figure 11, together with the white light image of all four samples. Images are recorded at the most intense Raman peak for each substance, 473 cm^{-1} for sulphur, 1347 cm^{-1} for DNT, 1043 cm^{-1} for AN and 1358 cm^{-1} for TNT (listed in order as they are placed on the brick in the white light image). At corresponding waveshifts, the images of sulphur and AN are both clearly enhanced as compared to the other samples. DNT and TNT can at first glance not easily be discerned from each other, this is due to the similarities of their Raman spectra. It is however possible to separate DNT and TNT if it is known that both substances could be present. By applying either correlation or least square fitting processing of the images, a false colour coded image can be produced to help user identification of type of threat substance found. The strong background suppression achieved upon using the imaging approach makes single particle imaging plausible. A fingerprint of sulphur particles on a brick has so far been successfully demonstrated, and with improvement in setup and data processing, explosives particles in general may well be detected. A paper on the hyper spectral imaging work is under preparation [17].

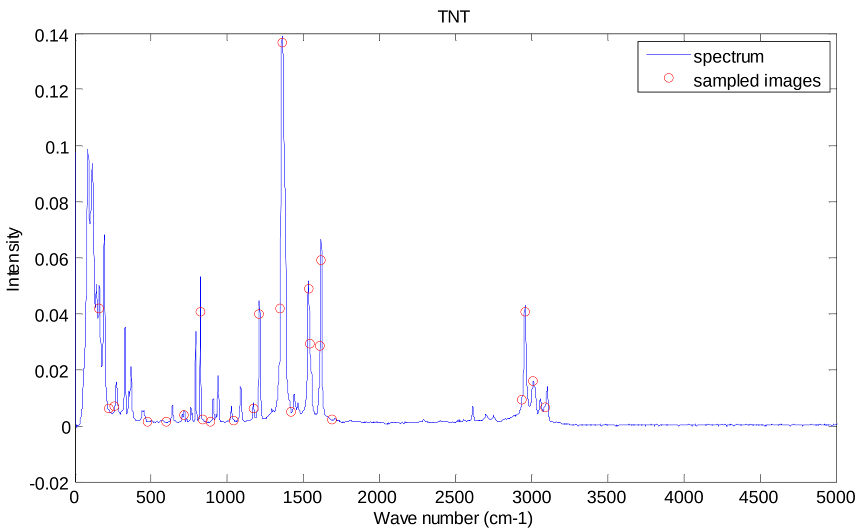

Figure 10: Raman spectrum of TNT. The red dots mark at which spectral points the monochromatic intensity images were recorded.

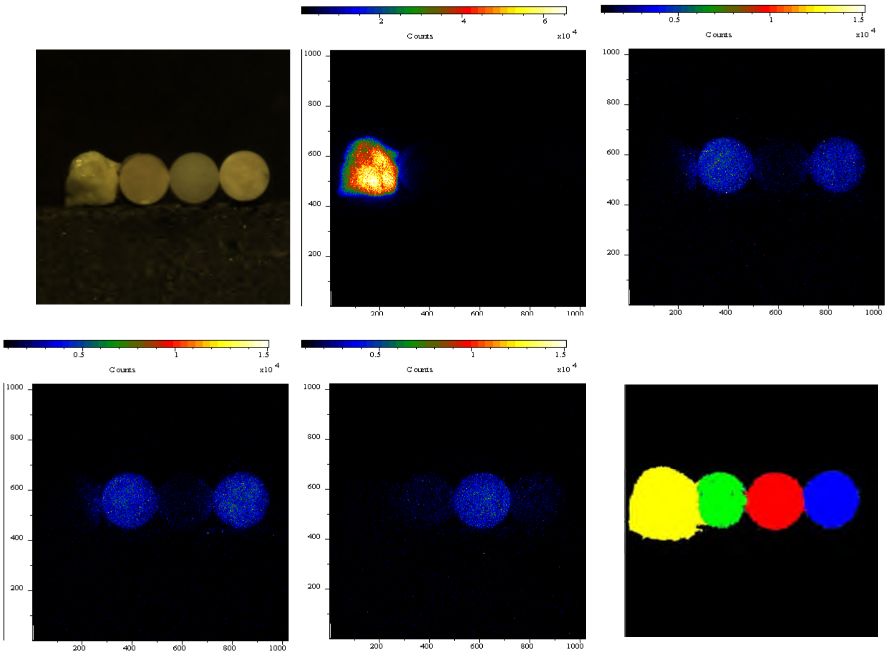

Figure 11: From top left to bottom right, in order; white light image of the four samples Sulphur, DNT, AN and TNT (in order as occurring), intensity image at 473 cm^{-1} corresponding to sulphur peak, intensity image at 1347 cm^{-1} corresponding to DNT peak, intensity image at 1043 cm^{-1} corresponding to AN peak, intensity image at 1358 cm^{-1} corresponding to TNT peak, false colour coding image where yellow represents sulphur, green DNT, red AN and blue TNT.

CONCLUSION

Raman spectroscopy has over the past years appeared as a strong candidate for species specific explosives standoff detection applications, although a limiting factor for its usefulness in real applications has been the relatively large amounts of explosives required for detection. There are however applications that do benefit from this capability – we have shown that standoff distances of hundreds of meters is readily achieved, even under complicating conditions such as through a window, or outdoors during heavy rain. To find concealed explosives and IED's, there is however a need to detect sparse particulate traces, or even vapors.

We have demonstrated that Raman imaging is a promising candidate for particle detection. The principle of using hyper spectral imaging has proven effective in suppressing background signal, and using high image resolution, species selective images can be produced. By turning to UV wavelengths, eye safe Raman imaging may be obtained, and ps based temporal filtering can be applied to reduce fluorescence, originating both from the background surface and from substances used in the explosives formula.

By utilizing resonance enhancement, we have shown that it is feasible to achieve explosives vapor detection, so far still in the ppm regime, but with potential for increased sensitivity – the measurement volume used was in the order of 4 cm^3, interrogating a larger volume will have a positive effect on sensitivity, as will the reduced self absorption expected from measuring on a vapor cloud in the open air.

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