Laser-Based Standoff Detection of Explosive Materials (LABSDEM)

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A scene after Mumbai train blasts

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Blast effect of an explosive planted in a vehicle

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Damage caused by explosives planted by terrorists

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The Threat

One of the most common forms of terrorism is the use of Explosives that has cost the lives of a large number of people in different parts of the world.

Hardly a day goes by without

- A suicide bomber’s attack,
- A car bomb,
- Planting of explosives at a public place etc.
The Threat

A low-budget terrorist can make deadly explosives from commonly available materials and amplify the killing power of his or her bomb with nails, nuts, or bolts.

Suicide bombers who penetrate crowded public places typically wear bombs that are easy for them to trigger.

We have to develop effective methods to detect these explosives at their pre-detonation stage.

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THREAT

- Attack is planned.
- Threat material is in place

RESPONSE

- Detect attack prior to detonation of explosives
- Move people out of harm’s way—take protective measures to prevent further loss of life
- Supply appropriate first aid and medical treatment

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The lives of the targeted people depend on the reliability of the explosives detection systems.

For a detection method to be reliable, it must prove to have a very high probability for detecting explosives if they are present.

There should be practically nil false negative alarms and very few false positive alarms.

Too many false positive alarms will make the personnel less apt to take these alarms seriously.
Commonly used Explosives by Terrorists

- RDX (1,3,5-Trinitro-1,3,5-triazacyclohexane)
- PETN (Pentaerythritol Tetro	
- HMX (Octahydro-tetranitrotetrazocine)
- TNT (2,4,6-Trinitrotoluene)
- DNT (Dinitrotoluene)
- Tetryl (Tetranitro-methylaniline-
  trinitrophenylmethylnitramine)
- Diazodinitrophenol (DDNP or Dinol)
- TATP (Triacetone triperoxide)
- HMTD (Hexamethyl triperoxide diamine)
- TATB (1,3,5-Triamino-2,4,6- trinitrobenzene)
- NG (Nitroglycerin),
- EGDN (Ethylene glycol dinitrate)
- ANFO (Ammonium Nitrate + Fuel Oil) and
- C-4 (composition of 91% RDX plus waxes and Oils)
# Standard, Improvised, and Plastic Explosives

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Name/Contents</th>
<th>Formula</th>
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<tbody>
<tr>
<td><strong>STANDARD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNT</td>
<td>2,4,6-Trinitrotoluene</td>
<td>C&lt;sub&gt;7&lt;/sub&gt;H&lt;sub&gt;5&lt;/sub&gt;N&lt;sub&gt;3&lt;/sub&gt;O&lt;sub&gt;6&lt;/sub&gt;</td>
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<tr>
<td>RDX</td>
<td>1,3,5-Trinitro-1,3,5-triazacyclohexane</td>
<td>C&lt;sub&gt;7&lt;/sub&gt;H&lt;sub&gt;6&lt;/sub&gt;N&lt;sub&gt;6&lt;/sub&gt;O&lt;sub&gt;6&lt;/sub&gt;</td>
</tr>
<tr>
<td>PETN</td>
<td>Pentaerythritol tetranitrate</td>
<td>C&lt;sub&gt;5&lt;/sub&gt;H&lt;sub&gt;8&lt;/sub&gt;N&lt;sub&gt;4&lt;/sub&gt;O&lt;sub&gt;12&lt;/sub&gt;</td>
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<tr>
<td>NG</td>
<td>Nitroglycerine (glycerol trinitrate)</td>
<td>C&lt;sub&gt;3&lt;/sub&gt;H&lt;sub&gt;5&lt;/sub&gt;N&lt;sub&gt;3&lt;/sub&gt;O&lt;sub&gt;9&lt;/sub&gt;</td>
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<tr>
<td>EGDN</td>
<td>Ethylene glycol dinitrate</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;H&lt;sub&gt;4&lt;/sub&gt;N&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;6&lt;/sub&gt;</td>
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<tr>
<td>HMX</td>
<td>1,3,5,7-Tetranitro-1,3,5,7-tetrazacyclooctane</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;H&lt;sub&gt;8&lt;/sub&gt;N&lt;sub&gt;8&lt;/sub&gt;O&lt;sub&gt;6&lt;/sub&gt;</td>
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<tr>
<td><strong>IMPROVISED</strong></td>
<td></td>
<td></td>
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<tr>
<td>ANFO</td>
<td>Ammonium <em>Nitrate</em> + Fuel Oil</td>
<td>NH$_4$NO$_3$</td>
</tr>
<tr>
<td>Urea Nitrate</td>
<td></td>
<td>CH$_4$N$_2$O$_6$ HNO$_3$</td>
</tr>
<tr>
<td>TATP</td>
<td>Triacetone <em>triperoxide</em></td>
<td>C$<em>9$H$</em>{18}$O$_6$</td>
</tr>
<tr>
<td><strong>PLASTIC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-4</td>
<td>RDX + Plastisizer</td>
<td></td>
</tr>
<tr>
<td>Semtex</td>
<td>RDX+PETN+Plastisizer</td>
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<tr>
<td>Detasheet</td>
<td>PETN + Plastisizer</td>
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TATP : Liquid Explosive

TATP is the hot favourite explosive of the modern-day terrorists.

It is one of the most sensitive explosives, susceptible to impact, temperature-change and friction.

TATP can be prepared using commercially available materials: acetone (nail polish remover), hydrogen peroxide (a bleaching and cleaning agent) and sulfuric acid.

TATP has been used by many suicide bombers including the shoe bomber (Richard Colvin Reid aliases Tariq Raja, who attempted unsuccessfully to blow up an airplane on Dec 22, 2001).

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Richard Reid – The Shoe Bomber

He was arrested on December 22, 2001 for attempting to blow up (unsuccessfully) the American Airlines Flight 63 from Paris to Miami with an intention to ignite explosives hidden in his shoes.

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Remote Detection vs Standoff Detection

• In remote detection, the personnel performing explosives screening maintain a safe distance from the explosive being screened, but the screening equipment does not.

• The use of an explosive sensor mounted on a robotic platform would be considered “remote” detection if the robot/sensor unit were sent to closely inspect a suspect site for explosives while the personnel operating this sensor remain far away so that they are not injured by a detonation.

• True “standoff detection” means that both the personnel and the equipment maintain a safe distance from any potential detonation. So the challenge is to develop detection technologies that can detect explosives at tens of meters away.

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Expectations from the Detection System

- Near real-time detection of traces of explosives at ppb and ppt levels,
- which are not only concealed but also placed in sealed/plastic containers,
- in ambient conditions,
- *in situ*,
- without the requirement of collection or preparation of the sample,
- with practically nil false negative alarms and very small false positive alarms,
- upto standoff distances of tens of meters.

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LIBS
Laser-Induced Breakdown Spectroscopy (LIBS)

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Laser Induced Breakdown Spectroscopy (LIBS)

• LIBS is a detection method that uses a laser with high energy enough to breakdown the sample into plasma.

• LIBS operates by focusing the laser onto a small area at the surface of the specimen. When laser is discharged, it ablates a very small amount of material in the range of 1 μg, which instantaneously superheats generating a plasma plume with temperatures of about 10,000 K.

• At these temperatures the ablated material dissociates (breakdown) into excited ionic and atomic species. During this time the plasma emits a continuum radiation which does not contain any useful information.

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Within a very small time the plasma expands at supersonic velocities and cools. At this point the characteristic atomic emission lines of the elements can be observed.

The delay between the emission of continuum radiation and characteristic radiation is of the order of 10 μs. That is why it is necessary to temporally gate the detector.
Emission and Collection Timing

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LIBS

- LIBS is a very sensitive technique, requiring as little as a few nanograms of some samples.

- LIBS spectra of several explosive compounds have been reported by many workers in the world.

- Standoff LIBS could be utilized with the proper telescopic focusing and collection optics.

- Some researchers have used LIBS to detect suspicious powder about a hundred meters away.

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Laser-Induced Breakdown Spectroscopy (LIBS)

Diagram of LIBS setup:
- Nd: YAG Laser with a wavelength of 1064nm
- Digital delay generator
- Collecting lens and optical fiber
- Focusing lens
- Plasma
- Sample on a stage
- Spectrometer
- CCD detector
- Computer for data analysis

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Prototype of double-pulse ST-LIBS System Capable of operating at a range of 60 m in the field
(Developed by Applied Photonics Ltd. UK)

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Advantages of LIBS Technique

• LIBS is a very sensitive technique with high spatial resolution (small focal spot). Many types of materials can be investigated including solids, liquids and gases.

• Vaporization and excitation of the sample occurs in one step.

• In majority of the cases no sample preparation is needed.

• LIBS provides on-line and real-time analysis of the sample, requiring no contact with the sample.

• Standoff LIBS could be utilized with the proper telescopic focusing and collection optics.

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Limitations of LIBS

- In a real environment there will be many interfering subsystems. The intended explosive surface may not be exposed. Other dust particles as well as parts of intended surface may be interfering with the result.

- There can also be contributions from nitrogen and oxygen in the air.

- Another possible problem is the peak intensity variations depending on the plasma temp. variations from shot to shot.

- It would be difficult to apply this technique to a vehicle or a cargo container where a large area would have to be scanned and any tiny fragments of material could easily be missed.

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Laser Induced Fluorescence

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Laser Induced Fluorescence

NO₂ & H₂O₂ Based Detection

Incident Light

Fluorescent Light

Spectral Signatures of NO₂ or H₂O₂

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Laser-Induced Fluorescence: NO$_2$ Based Detection

Limitations

- LIF spectra usually have no characteristic individual bands and the information is distributed over a wide spectral interval.

- The fluorescence profiles for molecules in the liquid or solid phase tend to be broad (several nm in the UV) due to vibrational relaxation. Hence the fluorescence signatures are not highly distinctive and identification based on fluorescence alone can be difficult.

- Another limitation of LIF is the problem of quenching of fluorescence due to the presence other contaminants.
Photo-fragmentation followed by Laser Induced Fluorescence : NO Based Detection

PF/LIF

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PF/LIF: NO Based Detection

- This detection concept is based on a single laser beam inducing a tandem process: photo-dissociation of explosive followed by highly selective detection of its photo-fragments having vibrationally excited NO radicals, utilizing laser-induced fluorescence.

- A laser pulse is used to fragment the explosive (referred to as PF, Photo Fragmentation). The fragmentation of nitro-based explosives leads to the formation of NO radicals.

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• The explosive is detected by monitoring radiation from the excited NO radicals.

• The fluorescence transitions of NO in TNT are in the spectral range of 225-240 nm, when the excitation wavelength is 248 nm.

• Since the atmospheric NO is not excited to any noticeable extent at room temperature, the interference due to atmospheric NO is significantly rejected in this technique.
NO (in TNT) is excited from $X^2\Pi (v''=2)$ to $A^2\Sigma^+ (v'=0)$
The fluorescence originates from $A^2\Sigma^+ (v'=0)$ to $X^2\Pi (v''=0,1)$

**Diagram:**
- UV Laser (248 nm)
  - NO (A$^2\Sigma^+$ ($v'$=0)) → NO (X$^2\Pi$ (v''=0,1))
  - Dissociation, NO is produced
  - NO is excited
  - NO$^*$ → Fluorescence Is Blue-shifted
  - Fluorescence 225-240 nm

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Figure 2: Spectra resulting from (a) DNT, (b) Crystalline RDX, (c) C4 and (d) Crystalline PETN.

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Raman Scattering

- Shift in frequency is the characteristic of the molecule of interest
- Has advantage of using a single-frequency laser for all molecules
- The major limitations of Raman scattering are that it’s weak intensity and background fluorescence can be a problem.
- The use of powerful lasers can lead to undesirable photo-decomposition of the explosive material and absorption of the laser can lead to fluorescence that can obscure the Raman signals.

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Resonance Raman Scattering (RRS)

• The problem of small Raman backscattering cross section can be overcome if one uses a UV pump laser to excite the sample to an actual excited level instead of a virtual level.

• The return signal under these conditions, known as “Resonance Raman Scattering (RRS)” is orders of magnitude higher than in the normal Raman scattering.
Resonance fluorescence differs from the Resonance Raman scattering in that the absolute frequencies of the fluorescent spectrum do not shift when the exciting radiation frequency is changed, so long as the latter does not move outside the absorption band.

The absolute frequencies of the Resonance Raman Scattering, on the contrary, would shift by exactly the amount of any shift in the exciting frequency, just as do those in the normal Raman scattering.
Detection by Laser Raman Spectroscopy

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Detection by Laser Raman Spectroscopy

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HYBRID SENSORS

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HYBRID SENSOR
CONCLUSION

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CONCLUSION

• There is no single technique suitable for the standoff detection of all types of explosives in different scenarios.

• A hybrid system, employing combination of these techniques, would prove to be the most effective system.

• Finally, there is always going to be a race in the adoption of newer technologies by the modern age terrorists aided by vested interests and the peace-loving scientists and technologists who want to defeat the evil design of these elements.

This has to be kept in mind.

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Thank You 
For Your 
Kind Attention

LABSDEM, Prof. (Dr.) Jai Paul Dudeja, Director, AILTO, AUG