ForLab Final Report: Scientific and technological results

FORLAB introduces several aspects of novelty:

- Although the selected analysis technologies are already existing technologies, all of them needed to be further developed to be fielded and to match the requirements of the forensic investigators at the post-blast scene.
- 3D imaging is also an existing technology already in use by security forces to document and investigate crime scenes but the objective of the ForLab was to develop this technology to make possible the generation and transmission of the 3D model of the scene in almost real time.
- ForLab introduces a new concept for the analysis of the post-blast scene based on real time availability of all the information gathered from the scene while the chain of custody of evidences is preserved.

The following paragraphs summarize achievements of the project on each of the technologies.

LIF as an screening technology

The fluorescence is the light spontaneously emitted due to transitions from excited singlet states to various vibrational levels of the electronic ground state.

Thanks to new technological development, Fluorescence Spectroscopy (FS) is now a widely used scientific tool promoted from the scientific field to a routine method for real time analysis in several experimental fields as biochemistry, biophysics, material sciences and forensic studies.

A typical experimental fluorescence sensor device, based on laser-induced fluorescence (LIF), is shown in Figure 1, with its main component being an optical radar, able to detect the emission induced by UV laser on remote surfaces; thus, several portions of the surface exposed to the laser light can be analyzed with high spatial resolution.

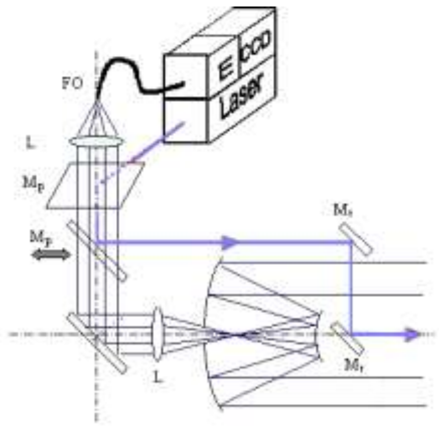

Figure 1 Components of laser induced fluorescence sensors for remote measurement

With specific reference to the analysis of a post blast scenario, the LIF technique can be used to identify special kind of debris having specific spectral signature, like parts of printed circuit boards and plastic material. Literature studies have shown that in general terms the LIF is not compound specific, however the additional capability of active reflectance measurements represents a significant step forward in the identification and precise localization of debris dispersed all around the crime scene. To fulfil these additional goals which are not specific of LIF system, the sensor will operate in at least two different modes by slightly changing the device set up (reflectance and fluorescence measurements).

Indeed the reflectance and fluorescence operating modes share most of the optoelectronic equipment, namely the collection optics and the spectral detector, while differing on one hand in the way the sample is excited, while on the other hand they differ in the way the spectral detector is operated.

Active reflectance measurements

Active reflectance measurements are based on elastic backscattering of the incident laser light: a spatial scan is performed while the laser is on. The collection optics is focused on to the scanned scene, and the acquisition camera operates with a high attenuation filter to avoid the saturation of the optical sensor. The result gives for each pixel of the scanned area the monochromatic reflectance intensity. Reflecting surfaces at normal incidence and irregular metallic debris as well are identified by proper processing algorithms.

Fluorescence measurements

The measurement of fluorescence spectra induced by laser is made by performing a scan while the laser light is on. The system uses a patent protected procedure to acquire spectra also in full day light: in this case a proprietary method is used to discriminate between the light induced from the laser (LIF signal) with respect to the light diffused by the area under study and by the environment. The result gives the fluorescence spectrum for each pixel of the scanned area; then a successive data analysis of the acquired spectrum provides detailed information on the area under study.

Analysis of spectral measurements

To speed up the data analysis on the acquired images, the most relevant spectral features are identified by Principal Component Analysis (PCA). Although it is commonly admitted that the PCs do not possess any direct physical meaning, they can nevertheless be represented as spectra suitable to be described in terms of bands. In some cases a given PC has a well defined spectroscopic band with associated peaks, while in other cases more complicated trends and shapes are observed: most frequent is the case of a band set against another. Few of the PC components are usually retained for subsequent analysis: typically 5 to 8 components are enough to describe the entire spectral data set. It is also worth noticing the possibility to build suitable linear combinations of the computed PCs to have a faithful representation of each pixel spectra, eventually used for the computation of standard CIE/lab colorimetric measurement.

The PCA devoted to the identification of prominent spectral features, relieves from the lengthy time consuming examination of each of the spectra acquired and can considerably shorten the time need to communicate with the Control Centre. The advantages of this procedure are that it is fast and can run in a semiautomatic mode, having though the inconvenience of requiring a global analysis, possibly ignoring those local peculiarities which do not possess enough statistical significance. To overcome this drawback local PCA can also be performed on different portions of the scanned areas, and then the results can be analyzed separately. Once identified, spectral bands are sought for in the acquired LIF spectra, completing the data analysis.

A different method used in the analysis of spectral images, concerns the identification of regions having a specific spectral content. Typical is the case of identification of a given pigment in an image: such tasks are accomplished either by a band analysis, or by using spectral mapper algorithms like SAM (Spectral Angle Mapper) or SCM (Spectral Correlation Mapper). Although the mapper algorithms perform well with a low computational cost, their performances are generally lower with respect to the band analysis procedures.

The LIF scanning system developed in ForLab has the following characteristics:

Parameter		***Value***
Operating mode		Image scan
Scanned area		64m2 at 10 m
Field of view		38 x 38 deg
Angular resolution		0.02deg
Spatial resolution		1 cm at 10m
Positioning accuracy		10 cm
CCD area		20x20 mm
Excitation wavelength		266nm up to 500prr
Energy per pulse		100mJ/cm2 at 10m
sensor		Multispectral 8 bands
Overall measurement time		8min
Weight		40Kg
Size		37 x 34 x 70 cm

Figure 2. LIF scanning system

LIBS and Raman as screening technologies

LIBS is an atomic emission spectroscopy technique used for the real-time, nondestructive determination of elemental composition and requires no sample preparation. The technique relies on the microplasma created by a focused laser pulse, typically several nanoseconds in length, to dissociate molecules and particulates within the plasma volume. The subsequent emission can be resolved spectrally and temporally to generate a spectrum containing emission lines from the atomic, ionic, and molecular fragments created by the plasma. The LIBS technique yields detailed information on elemental compositions, including many minor and trace elements.

Nowadays, laser-induced breakdown spectroscopy (LIBS) has been shown to be a suitable technology for detecting the presence of organic material and in some cases determining the type of organic material. Applying LIBS to energetic organic material detection and identification is of interest for various applications, including force protection, security concerns, forensic analysis, etc. Other LIBS applications are analysis of environmental, archaeological, geological materials and use in artwork analysis.

Raman spectroscopy is a spectroscopic technique used to study vibrational, rotational, and other low-frequency modes in a system. Typically, a sample is illuminated with a laser beam. Light from the illuminated spot is collected with a lens and sent through a monochromator. Wavelengths close to the laser line, due to elastic Rayleigh scattering, are filtered out, while the rest of the collected light is dispersed onto a detector. Chemical species that exhibit a change in polarizability with vibration exhibit Raman spectra that are uniquely determined by their vibrational mode structure. Analytical techniques based on Raman spectroscopy have been widely used for explosive detection and characterization. Raman has been demonstrated for analyzing minerals, use in artwork analysis, etc.

In the ForLab project a new portable system combining LIBS and Raman analysis capability has been be designed and developed with the following characteristics:

- Two modes of operation as table-top equipment or as backpack to be able to access and analyze samples that are difficult to reach
- Capability to detect different types of explosives directly on different surfaces or using a swab
- Analysis time, including automated response in less than one minute
- There is no contamination of the detector and therefore continuous operation is possible
- Designed to avoid cross contamination between samples.
- Capable of automated detection of particles of 90 ng of explosive with LIBS and particles with diameter of 300 µm with Raman
- Easy to update Raman substance database for identification
- Capability of detection of gunshot residues (GSR) on standard sampling kits and other surfaces, providing a reliable result in less than one minute.

Technical data:	
Dimensions	54.5 x 35 x 23 cm
Weight Body	23 Kg
Weight Header	3.5 Kg
Start-up time	5 min
Analysis time	Single Shot: 3 sec Burst (10 shots): 30 sec
Pulse repetition rate	0.5 Hz (2 s)
Autonomy	> 4 h

Figure 3. LIBS-Raman system developed in ForLab

During the final tests of the project the LIBS system achieved outstanding results being able to differentiate samples containing residues of the explosives from samples not containing residues (or in a quantity below the limit of detection of the system) in all the three scenarios.

NLJD for detection of electronic debris

The foundation technology (NLJD) was previously developed to detect small electronic components used in eavesdropping systems and electronic bugs and has been well known for over 30 years. This technology is based on the intrinsic property of non linear junctions such as those contained in semi-conductors, to radiate different harmonics, when radiated at a given frequency. It provides the ability to detect electronics, even if switched off or in sleeping mode.

The electronic components are detected in real time by measurement of the 2nd and the 3rd harmonic levels. Localization of electronic debris will be obtained using a man-portable NLJD detector. When the operator detects an electronic device, he pushes a button to inform the Command and Control Center that the current NLJD detector position within the 3D scene corresponds to the position of an electronic device. The position of the NLJD detector will be determined thanks a 3D scene reconstruction performed by a dedicated platform implemented with a LIDAR (Astrium's contribution to the Forlab system). This platform is man-portable and has to be moved to different positions so that the LIDAR measurements can be combined to build up the 3D scene.

The precise position of the NLJD detector into the 3D scene, taking into account the sweeping movement of the operator scrutinizing the area will be obtained by a Kinect camera.

Figure 4 The full system with the NLJD scanner

3D Scene modelling for forensics

The start of any forensic investigation must begin with the collection, review, and analysis of evidence. The better the quality of evidence, the better the analysis and likelihood of solving the crime is.

Although photogrammetric techniques using cameras, tripods are regularly used, the trend today is to use directly 3D laser Scanning technologies. It is an ever growing and useful application of laser based measurement technologies in fighting crimes and reconstructing events.

Often referred to as High Definition Surveying (HDS), 3D scanning became popular in the late 1990s. Some scanning technologies are based on optical methods whereby photographs are used to collect and match points in corresponding photographs (i.e. Photogrammetry and stereo matching) while the lesser known CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) allow the interior structures of objects to be "scanned" and examined.

The more common 3D Lidar (Light Detection and Ranging) scanners emit a beam of light and measure the part of the beam that is reflected back to the instrument. These are the most common types of scanners being able to collect and preserve data from very large crime scenes.

The two most common types of Lidar scanners are “phase-based” and “pulse-based” scanners, which refer to the method for determining the distance to any surface that has been scanned.

Compared to classical approaches HSL techniques, allow acquiring data in detail without predetermining what is and what is not evidence. It allows scanning organic shapes and highly curved surfaces that would otherwise be difficult to measure (ex of bloodstains evidence spanning over several surfaces, furniture, and walls).It can physically reach point of measurement without touching, deteriorating or contaminating it. Most measurements can be done from a safe distance but equipment operators and the general public should be at safe eyes distances. real-time visual feedback as the points are being captured, are possible making the scene immediately available for review and analyzed at the scene. Areas lacking detail can then be re-scanned while other areas that did not scan properly can be addressed.

However, level of Required Accuracy depends on the practical range in given conditions. Some reflective surfaces, dark/highly absorptive surfaces or oblique surfaces may not provide any or good data. Registration errors, when combining several scans in one large point cloud, need to be considered.

There is now a migration towards photorealistic 3D environments where millions of points can be measured and analyzed. 3D scanning is still relatively new and costly so that other capable technologies such as photogrammetry, should be also considered as well as combination of the two.

The greatest area of development will be in the available software tools for the analysis and visualization of scan data. Some of these tools apply to bullet trajectories, bloodstain pattern analysis, and even "image projection" where a suspect's height can be estimated from security videos. Once the analysis is complete, the results can be immediately displayed as a 3D animation or through an interactive viewer for court presentations. Eventually, the benefits of 3D scanners and related analysis tools will become more familiar to law enforcement agencies, attorneys, and jurors.

The ForLab project developed the capability to produce 3D models directly on the field in an iterative way.

Figure 5. 3D modelling tool developed in ForLab

The Innovations of the approach are:

- Acquiring rapidly 3D models and not simply 3D surfaces or 3D geometric points, with the challenge of processing the data directly on the spot in order to deliver near real time data to the Command & Control Centre.
- Acquiring not only geometry and radiometry, but also semantics and eventually topology
- Allow easy integration (geo-localisation) of any complementary detections and measures without needing specific set-up on the scene (position reference patterns…).
- Allow rapid deployment through acquisition planning on the spot and rapid set up: typical deployment timing would be around 10 minutes, with acquisition lasting a few minutes, and the redeployment taking a few extra minutes.
- Specific tool to optimise the acquisition process to limit the number of acquisitions while preserving minimum occlusions.
- Ability to produce even from data with occlusions, complete 3D model with occluded areas interpreted: even if we do not see the floor behind the chair, or the wall behind the car, we can rebuild the floor plane or the wall plane to produce a complete 3D model.

Sample position reference indoor and outdoor

Autonomous tracking and localization approaches that do not rely on GPS are becoming very attractive the last years especially for indoor navigation. The main characteristics of autonomous tracking systems, are deployment time, accuracy, portability and reliability. Moreover these systems ought to be pervasive and require zero interaction with the users.

Depending on the target application different requirements for each characteristic are needed, and as a result, radically different systems can be developed that depend on different working principles and are of different cost. The core design choice that serves different requirements, is the point –to-point distance measurement. This can take place by inferring distance, using physics laws, from measurable natural phenomena like sound time-of-flight, electromagnetic signal time-of-flight, electromagnetic signal angle of arrival, electromagnetic signal strength. Depending on the physics formulas that associate the aforementioned measures with distance, the achievable level of accuracy is determined. For instance, time-of-flight can be easily associated with distance because speed of sound and speed of light are well measured, stable and a simple formula associates them with distance. On the other hand, signal strength depends on a variety of factors that is very difficult or impossible to measure, and the distance association approach is to take indicative measurements and implement curve-fitting maths. The latter approach radically affects the deployment time because it requires a training stage, where the user needs an additional different method to measure the distance in order to train the system and accuracy can vary at runtime because several factor can affect received signal strength. But, there is no free lunch, what is straightforward to compute using robust physics formulas is very hard to measure in practice. More specifically, the light speed of electromagnetic signal requires clocks with picoseconds accuracy so that reasonable accuracy (10cm) is achievable. Current state of the art processors cannot compete with required performance, so application specific hardware accelerators are required to implement baseband processing which along with very sophisticated algorithms result in very expensive devices. In ForLab UTH implemented 2 approaches for the measurement of distance between 2 points:

- **Option 1**: Received Signal strength of 802.11n (CSI metric) for low-end devices
- **Option 2**: Signal Time of Flight using Ultra wideband(UWB) which was used in the final system and demonstrated in Linares.

These diverse systems achieved the following performance for distance measurement:

Main specifications of **option 1 RSS**:

- deployment needs training (20 min)
- 60 meters is the maximum distance that can be measured between 2 points.
- Accuracy of 1-2 meters
- Very cheap (30 € per device)

Main specifications of **option 2 ToF:**

- deployment does not need training
- 120 meters is the maximum distance
- Accuracy of 10 cm
- Relatively expensive (600€ per device)

Another important subsystem of the localization module is the tracking solver which uses distances and known anchor Cartesian coordinates to provide the Cartesian coordinates of a point on any mapping system. The main job of this module is to solve a system of non-linear equations that associate the given point with the known anchors. The math are standard and based on Non-linear least square solving approaches which come in several flavours. UTH thoroughly explored several localization areas solution space using different solving algorithms to determine their performance and appropriateness for the specific type of problem. Moreover, they have developed a novel methodology to detect a faulty distance measurement when the number of anchors is more than 3 and exclude the faulty measurement for the calculations. The approach is based on solving all possible combinations in pairs of 3 and inspect the convergence effort which indicates when a problematic measurement affects the solution region. The specific algorithm detects faulty measurements in 90% of the cases and is in the core of a patent application.

The final ForLab system field requirements lead to the adoption of option 2 for distance measurement. More specifically, the final system specifications are as follows:

- Position Accuracy 10cm
- Automated alignment with a any coordinates reference
- Minimum deployment requires 4 anchors (arbitrary placement)
- Minimum coverage 10.000 square meters (100m x 100m area)
- Response time depends on a number of concurrent devices.
- Each device introduces a 20msec delay for (1 second for 5 devices)
- 8 hours non-stop operation on batteries
- Weight of a ruggedized full set with batteries, 4 anchors and 4 location devices is 5kg.
- Prototype cost of a full set 12.000€ (8 devices).
- Average deployment time 15 minutes (needs trained personnel)
- Proven field operation (under rain)

Figure 6. Anchor points and positioning module in the office scenario

Command and control centre (Knowledge Management)

“Command and Control” addresses the arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander or a command center in planning, directing, coordinating, and controlling resources and operations in the accomplishment of a mission.

“Operations” deals with the way the operational process and procedures are conducted by users and deciders using many data sources to support decisions and to optimize results.

“Communications” looks into the way the data and commands are shared and transmitted among many sources and users linked together to support decisions.

“Knowledge Management” consists of:

- Sensor fusion for prediction and estimate of system internal states by optimal stochastic filtering of system and sensor dynamic models with real measurements, and
- Data integration, management, merging, analysis and exploitation of the multiple sources of data to support decisions and how deciders can interact with the data.

Command and Control Center

A Command and Control Center is typically a secure facility that operates as dispatch, surveillance monitoring, alarm and coordination office center. A command and control center that is used in a deployed location is usually called a command post.

Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling operations in the accomplishment of a mission.

Commanding officers are assisted by specialized staff officers and personnel. These staff provides a bi-directional flow of accurate, timely information between a commanding officer and subordinate field teams, which by category represents information on which command decisions are based.

The key application is that of decisions that effectively manage resources. While information flow toward the commander is a priority, information that is useful or contingent in nature is communicated forward to lower staffs and field teams.

The ForLab project developed plug-ins to:

- Enable forensic investigation professionals shall be guided through the scene.
- Enable presenting an overview of the scene that the professionals are involved in.
- Enable presenting possible evolutions of the situation based on the collected data.

Using visual navigation for after action analysis shall help:

- Professionals to perform more detailed debriefing of data and procedures leading to improved future operations.
- Better prevention and mitigation of risks.

The main novelties of the ForLab project with respect to command and control centre will be to:

- Bring state of the art decision making command and control techniques using:
    - Dynamic modeling of data collection sensors supporting command and control centre
    - Explore and model detailed application requirements that shall drive technology development
- Bring into the system data and information management for collected data reduction, browsing and rapid access.
- Bring system indexing of large scale distributed data

Data Integration and analysis

A data system must also be capable of integration, management, merging, analysis and exploitation of data, which in turn can be very complex due to the multiple nature of the different data and their sources. Besides, conflicts and multiple-access are also very common in the operational scenario due to wrong data, multiple sources and source conflicts in redundant data.

Data fusion is composed of a set of subtasks that filter, transform, reorganize and optimize data. Common Data fusion operators are: Minimum union, Full Disjunction, Complement Union, Merge and Priority Merge, Match Join and Group and aggregation

Although the engineering literature is replete with examples of how data fusion techniques are being applied in military and industry projects, they are just now beginning to be applied to many kinds of projects. Their integration is a challenge in order not only to optimize the data produced by them, but to improve their own work process.

The main novelties of the ForLab project with respect to data fusion, integration and analysis will be to address the:

- Server
    - AMQP message broker (RabbitMQ)
    - Key-based distributed data store (RiakCS)
    - Application modules coordinated through AMQP
    - REST service
- Client
    - Eclipse RCP based product
    - 3D renderer and scene management
    - Graphing, multi-windowing, cross-platform

- Capabilities:
    - 3D scene with in-situ evidences and aerial view
    - Data visualizations for each sensor
    - Rich client and mobile client
- Use of data:
    - Replay investigations
    - Simulated investigations

- Integration:
    - Standards based messaging and plug-in architectures
    - Distributed processing and analysis

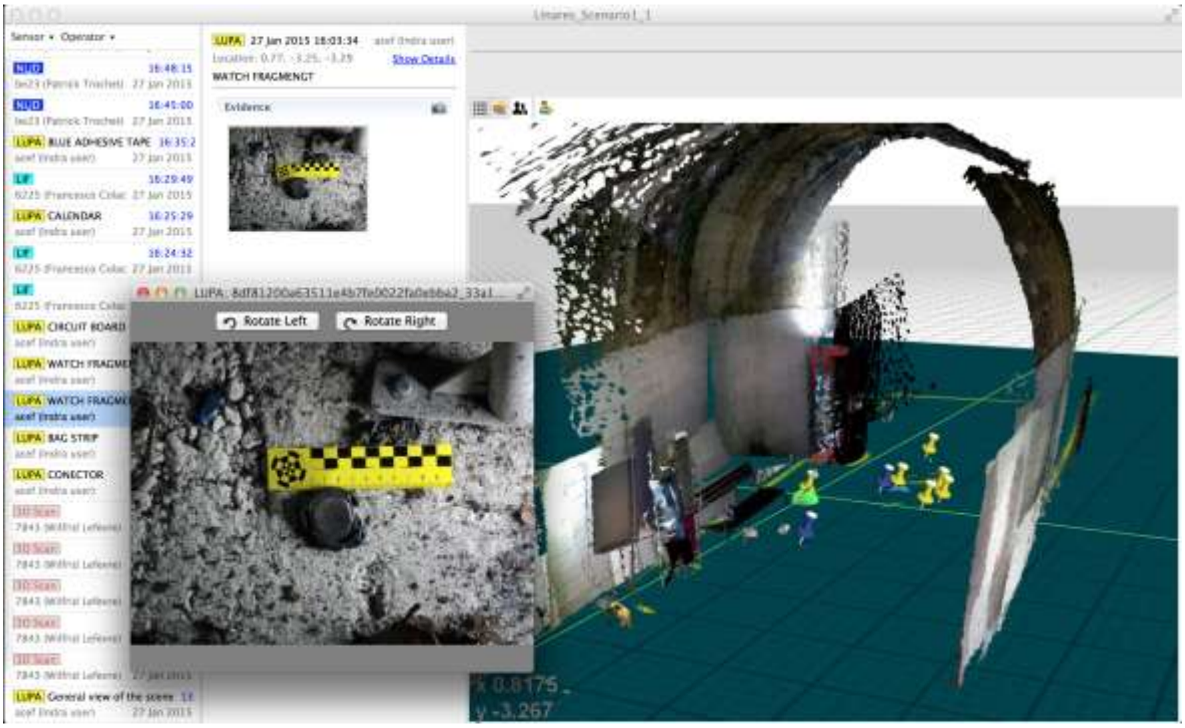

Figure 7. Screenshot of the C&CC. Metro station scenario