2-D/3-D LADAR Experiments in Urban Environments for Cooperative and Non-Cooperative IFF

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1.0 BACKGROUND

Combat Identification is extremely complex for today's asymmetric warfare conducted in urban environments. There is still the military need to reduce fratricide to extremely low levels, but now it must be accomplished in the presence of much more complex environments, with considerable clutter, where hostiles are mixed with neutrals and where there is a continuing need to make a positive hostile ID before action can be taken. Recent conflicts (OEF, OIF) have demonstrated how any enemy can not only blend into the surroundings but also take advantage of civilian populations in urban areas to screen their operations and restrict the friendly forces from readily responding to threats. Just a look at a typical scene from a residential area in Baghdad, figure 1, gives an indication of how restricted the line of sight can be (even for airborne assets), and how many opportunities the hostiles have to hide their operations.

Figure 1: Residential area in Baghdad.

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There are of course even more complicated urban environments with deeper urban canyons and a more dynamic mix of vehicles. Since it is likely that NATO forces will have to operate in these environments in the future, it is reasonable to re-examine the CID work performed to date and investigate how to improve Combat ID capabilities in the future. This paper discusses the problem, and describes several 2-D/3-D LADAR options currently under investigation by NATO SET 077 Research Technology Group -45 that can improve the capability to contend with these complicated problems in the future. The paper also touches on a non Line of Sight approach to Combat ID being explored by RTG-45 member nations.

2.0 DESCRIPTION OF THE SCENARIO

In contrast to current cooperative combat ID systems that typically operated best in open combat areas (e.g. the deserts of the middle east), the urban environment presents several unique challenges. First and foremost it is a complex mix of friendly, hostile, and neutrals elements all dynamically mixed in a highly cluttered and complex environment. Next although the enemy exists in substantial numbers, they are not organized like conventional forces and tend to operate in small groups using hit and run tactics rather than taking a stand defending a fixed position. Because the enemy is free to choose when and where to strike he can appear rapidly, deliver his weaponry and then disappear into the masses. So the hostile force can be very close (small separations in angle and range) to friendlies and neutrals and make the best use of the urban environment to hide their actions. In the urgency of these conflicts it is still possible for friendly forces to mistake each others positions and casualties can result from friendly fire. In general this is exacerbated in the presence of RF jammers used to defeat IEDs, which can inhibit radio communications, and introduce a higher level of uncertainty into operations. Although no current sensor approach reduces exposure to ever present threats such as IEDs and ambushes to the desired levels, there are technical solutions for reducing fratricide, and moving Combat ID sensing (and therefore decision making) to longer standoff ranges. Typically sensors have line of sight restrictions, which restrict their effectiveness in urban environments. There are now evolving technical means available, which can extend detection and identification to longer ranges without demanding line of sight to the target. This will allow weapons to be used at their maximum effective range, providing friendly forces an advantage. In particular there are many types of Laser Radars (LADARs), which can provide extended range identification in urban environments both cooperatively and non-cooperatively. While identification of friendlies can be addressed with cooperative ID systems, resolving the Hostile/ Neutral mix will require non-cooperative combat identification (NCID) approaches. NCID will have to be at high confidence levels to be useful, and whenever possible be performed automatically. Cost will be a driver, as well as an ability to provide identification information at any time of day, and under aerosol obscuration. In order to achieve this, NCID must be highly directional and able to sort targets in range. The options for achieving cooperative and non-cooperative CID are described in the following sections.

3.0 CURRENT NATO COOPERATIVE CID APPROACH

NATO Standardization Agreement (STANAG) 4579 describes a millimeter wave (MMW) system called the Battlefield Target Identification Device (BTIDs) for providing cooperative combat ID capabilities to properly equipped forces. Although the development of this approach has been pioneered by the United States Army, the United Kingdom and France have built versions of this hardware for operational testing. There is a modeling and simulation test bed developed for evaluating this system as well as joint field exercises conducted with participating NATO nations. The BTID hardware is shown in figure 2.

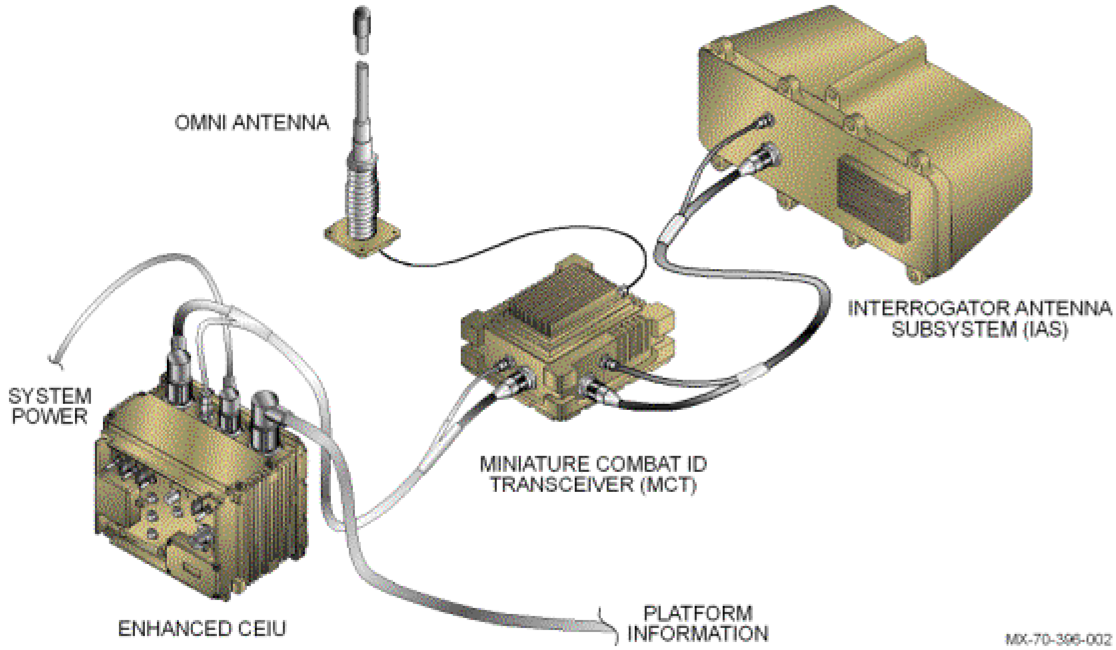


Figure 2: BTID hardware.

Although this MMW system is a product of a lengthy and expensive development process it is totally mismatched to the urban environment. It utilizes broad beam (degrees) millimeter wave interrogators, which cannot discriminate in angle or range in the presence of urban clutter. Even worse is the uniqueness of this frequency so that the operation of it immediately betrays the presence of friendly forces. Of course the effects of multi-path in urban environments will be so severe there would never be a reason to turn it on. In the typical urban geometry is shown in figure 1, the MMW main lobe will intersect buildings at relatively short ranges and the multi-path created will defeat the systems capability to sort targets in angle. The side lobes which have an even larger angular extent (which can dominate the return at short ranges) will be considerably worse in generating these multipath returns.

As a method to keep the costs for this system to affordable levels the MMW system has no inherent capability to discriminate returns in range, so the information for determination of which vehicle is responding to the interrogation in range is lost. Rather than dwell on the shortfalls in this still not deployed MMW approach, the following section will describe a cooperative CID approach pioneered by the member nations of RTG-45 under a previous NATO group (Technology Group (TG)-11).

4.0 LASER+RF/ RF COOPERATIVE COMBAT ID SYSTEM

There is a common targeting and fire control approach used by aircraft and armored vehicles when attacking vehicles. The primary target acquisition and fire control sensor is based on the visible (television) and infrared (FLIR) portions of the spectrum. So, whether it is a FLIR/TV integrated into tank or helicopter gunners primary sight, or a pod mounted FLIR /TV on the wings of a modern jet aircraft or UAV the sensor performance is similar. The FLIR/TV system detects the presence of a suspected target due to thermal characteristics (hot spot on FLIR), motion characteristics, approximate shape and size. Typically these systems have a wide field of view (also lower resolution) search capability, coupled with a narrow field of view (higher resolution) recognition capability. Potential targets are detected at much longer ranges than they can be recognized and this is the area where a cooperative CID system can greatly aid the operator in successfully deploying his weaponry at the maximum effective ranges. Because of the passive acquisition sensor's angular resolution, the attack platform can locate the targets position very precisely in two dimensions (angle/angle). The platform uses this information to direct a laser rangefinder (or designator) at the target to complete the fire control solution for a variety of weapons (tank guns, conventional ordnance, guided weapons). The laser pinpoints a single target with a precision that matches the FLIR/TV acquisition sensor angular resolution, and therefore can be used to select a single target at the maximum effective weapon ranges.

There are CID approaches that only use the laser and a laser detector and either code the laser interrogation or code its reflection. Although these approaches have been successfully demonstrated, they require a laser modification, and a two-way laser path is required to establish ID. The laser modification is a cost driver, and the 2-way path requirement can result in reduced range performance in obscurants or in reduced visibility conditions for our current rangefinders and designator. Additionally, if the laser is not used for coding the message then an alternative would be to send a companion RF encrypted message. This is the approach that Mr. Bill Otto at MICOM (now AMCOM) patented, where the existing communication link (UHF or VHF) is used to transmit a nearly simultaneous (with the laser transmission) encrypted interrogation message to the target. A friendly target, after receiving the near simultaneous laser and RF energy, then uses his RF link to make an encrypted reply giving vehicle ID and position based on its Global Positioning System (GPS) information. This process is described in figure 3, showing a block diagram for this Laser+RF/RF approach. Although discrete hardware boxes were used to support the demonstrations of this technique, actual implementations would only involve software changes to aircraft computers already embedded in the platform. Ground vehicles would require the addition of laser detection systems, which are available in a wide variety of capabilities and prices.

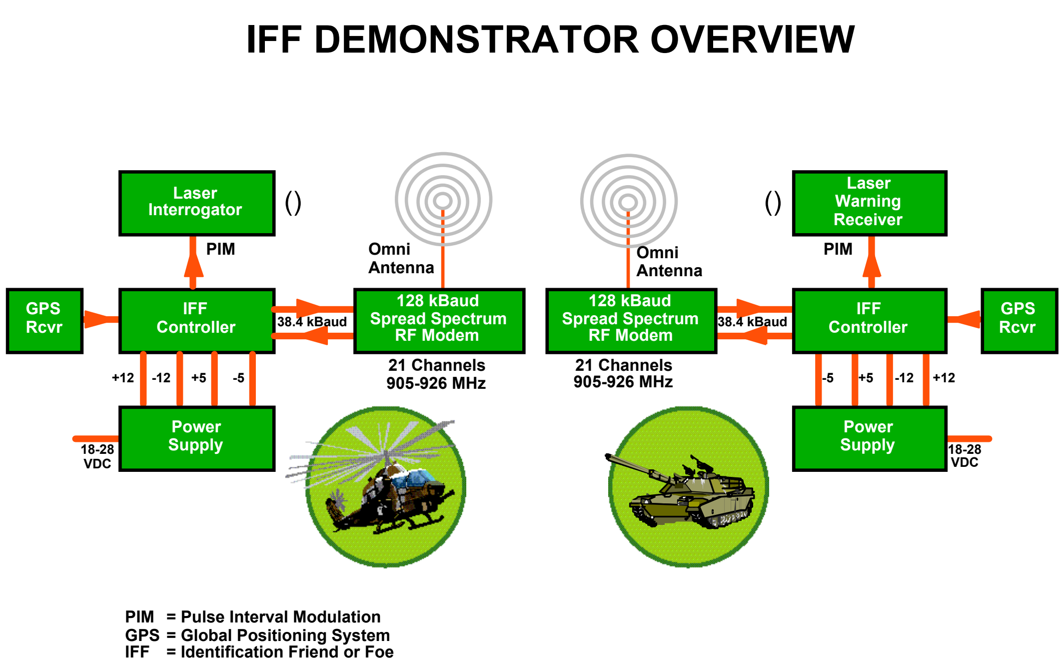


Figure 3: LASER+RF/RF block diagram.

Five NATO nations built and tested these LASER/RF systems in a joint exercise held at the Polygone in Captieux, France in 1996. The test resulted in over 10,000 cooperative LASER/RF interrogations with an overall success rate in excess of 95%. After this successful ground trial the U.S. Navy embarked on a series of aircraft integrations to evaluate the maximum range performance and sorting capability of this approach. The first flight test was on an AV-8B aircraft using the F/A-18 FLIR pod. This test series successfully demonstrated very long range (20.7 nautical mile) interrogations and replies, with 95% correct ID, and target separations as close as 65 meters. The next integration was on the F-14D using the LANTIRN pod with its eyesafe laser rangefinder. The energy in the eyesafe mode is considerably less than eye hazardous laser mode, and the maximum range demonstrated was 7 nautical miles.

Then ONR and the USMC combined to support a field trial which included modifying 4 M1A1 tanks and an AH-1W Cobra Helicopter with the LASER+RF/RF combat ID capability. This culminated in a 2-week test series conducted at the NAVAIR WD ranges, and produced impressive results. The AH-1W helicopter obtained over 95% correct IDs out to 10 kilometers, with vehicle spacings as close as 50 meters. Correspondingly the M1A1 obtained over 99.2% correct IDs out to 10 kilometers. Both platforms had reduced success rates in the presence of heavy battlefield obscurants, but as long as the laser rangefinders on these platforms produced valid range returns from the target (a requirement for committing a weapon), the LASER+RF/RF system always worked.

NATO has supported other Combat ID studies and tests and one of these was the Long Term Scientific Study (LTSS)-45, which evaluated a wide variety of cooperative and non-cooperative approaches over all of the possible scenarios (air to air, air to ground, ground to air, and ground to ground). One of the conclusions reached in this study was that a LASER/RF CID approach had the highest utility across all the platforms of interest, including the dismounted soldier. Again the wide spread deployment of laser rangefinders and RF communication systems across all military platforms, was a major driver for this broad utility level. Another CID test sponsored by NATO was titled the “ Four Power CID trials” hosted by Germany in the Meppen armored vehicle proving grounds. Again a LASER/RF approach (fielded by Germany) demonstrated 100% probability of successful combat ID while meeting all the field test requirements including operation in obscurants using an eyesafe laser source.

A comparison of the BTID (NATO STANAG 4579) and an LASER+RF/RF approach for urban environments is shown in Table 1.

Table 1: NATO STANAG 4579 and an LASER+RF/RF approach for urban environments

OPTIONS	STANAG 4579	LASER+RF/RF
System	BTIDS	LIFES
Operating	Millimeter Wave	LASER + UHF
Angular Res.	Degrees	Milliradians
Range Res.	None	10 feet
Demo	M1A2, Bradley	M1A1
Aircraft	None	AV-8B, F-14, AH-1W
Status	Freq. Alloc. Issues	Based on deployed lasers & radios

5.0 LASER/RF COOPERATIVE CID FOR DISMOUNTED SOLDIER

The Institute for Defense Analysis (IDA) was tasked by DoD to investigate military operations in Urban environments. They formulate the perceived needs for military capabilities in urban environments from interviews with returning field commanders, and reading field reports. Although vehicle to vehicle fratricide (after moving into the urban environment) has been low, the issue of friendly fire against dismounted soldiers is perceived as a critical problem. To address the critical CID issue highlighted by the IDA review of this area, the Army has envisioned a LASER/RF system for the individual soldier. It would be composed of an eyesafe-interrogating laser (potentially with a secure code of the day) attached directly to the rifle (or other hand held weapon), which would send a laser message to the intended target. A suitably equipped friendly would have a laser receiver, which detects the encrypted laser interrogation and automatically sends an RF reply over a small hand held radio. The shooters radio would then put a message on the weapon sight indicating the target is a friendly. This is shown pictorially in figure 3, with an early system developed to show proof of principle. The Army calls this system the Dismounted Soldier Identification (DSID) system, and is expected to become part of the Land Warrior soldier's suite of equipments being developed under the Future Combat Systems.

Figure 4: DSID Land Warrior Combat ID.

The following sections describes non-cooperative approaches which will also use the deployed pulsed laser systems and can operate as well with the coming generation of eyesafe laser systems.

6.0 NON-COOPERATIVE COMBAT ID REQUIRED IN URBAN ENVIRONMENTS

The introduction of large numbers of neutrals into the vicinity of conflicts, and the presence of hostile forces who have no compunctions regarding the loss of neutral lives greatly complicates CID. In many cases friendly forces will be required to use their weaponry to respond to hostile fire, but will be inhibited in taking full advantage of their firepower because of the uncertainty of the hostiles position in the presence of neutrals.

Obviously this problem moves beyond what any cooperative system, which only identifies friendlies, can be expected to provide. So what will be required is a non-cooperative approach to sorting friends, foes, and neutrals (IFFN), with high reliability and low false alarm rates. What are some of the discriminants that can be used to rapidly sort hostiles and neutrals? Some obvious indicators would be the presence of weaponry on individuals, or the detection of fire from individuals. Of course ideally the friendly forces want to perform combat ID at ranges outside the enemies effective weapon range, and at ranges long enough to make maximum use of their firepower. So they need to move Combat ID to the longest possible ranges

Although ideally these non-cooperative combat ID systems should be available to the individual soldier, initially they will be deployed on manned and unmanned platforms (airborne or land vehicle) due to their cost, size, and weight. The Marine Corps already operates with the Dragon Eye UAV and the Army the Raven UAV at the platoon level, and the goal would be to make sensors that would be compatible with these types of platforms shown in figures 5 and 6 below.

Mission Description(s)	USMC Light Infantry, Dismounted Urban Warfare
Features	Small Size, Light Weight, Bungee Launch, Waypoint Nav., Laptop Mapping, RS-232 Interface
Payloads	CCD Color Video, 2 Camera Switcher, GPS (C-Code), Altimeter, Air Speed Sensor
Range	5 km
Endurance	53 min. (Primary)
Speed	65-80 kmph, 35-45 knots
Operating Altitude (Typ.)	100-500 ft AGL, 30-150 m
Span	1.2 m
Length	0.9 m
Weight	2.6 kg
Launch method	Bungee
Recovery method	Conventional Horizontal Landing

Figure 5: USMC Dragon Eye UAV.

Mission Description(s)	Light Infantry Military Operations on Urbanized Terrain (MOUT), Dismounted Urban Warfare
Features	Small Size, Light Weight, Hand Launch, AutoNavigation, AutoLand, RS-232 Interface
Payloads	CCD Color Video, 2CCD Switcher, IR Camera, GPS (P-y Code), Altimeter, Compass Heading
Range	10 km
Endurance	90 mi. (Rechargable), 80 min. (Primary)
Speed	45-95 kmph, 25-50 knots
Operating Altitude (Typ.)	100-500 ft AGL, 30-150 m
Span	1.3 m
Length	1.1 m
Weight	1.9 kg
Launch method	Hand Throw
Recovery method	Deep-Stall Vertical Landing

Figure 6: U.S. Army Raven UAV.

Larger systems with longer effective ranges could be used with larger aircraft providing close air support to the ground forces. As the requirement for combat identification moves to longer ranges, the challenge for Non-cooperative Combat Identification (NCID) systems will be cost and complexity. So a significant cost saving can be realized by using the already deployed lasers.

The current combat ID capability based on adding visual cues (e.g. colored boards, IR panels) to friendly targets are easily compromised and exploited by this rapidly evolving enemy. So we must look beyond these measures to systems, which can capture the unique aspects of targets for determining allegiance at detection ranges. There are a variety of laser-based approaches, which can contribute; to resolving these combat ID challenges and they will be discussed in the following section.

7.0 LADAR NCID OPTIONS

Lasers can be used to interrogate targets to extract a wide variety of information that is applicable to combat ID. As shown in figure 7, we have considered 3 of these options for consideration for Urban NCID. The first 2 options (2 and 3-D imaging) use currently deployed laser systems (and have already been demonstrated with future eyesafe lasers as well). The third option (laser vibration sensing) uses highly reliable lasers developed by the telecommunication industry. The shift to eyesafe wavelengths (1.4 to 1.8 microns) also results in better penetration of natural and man-made obscurants providing even longer effective ranges for these non-cooperative combat identification Systems.

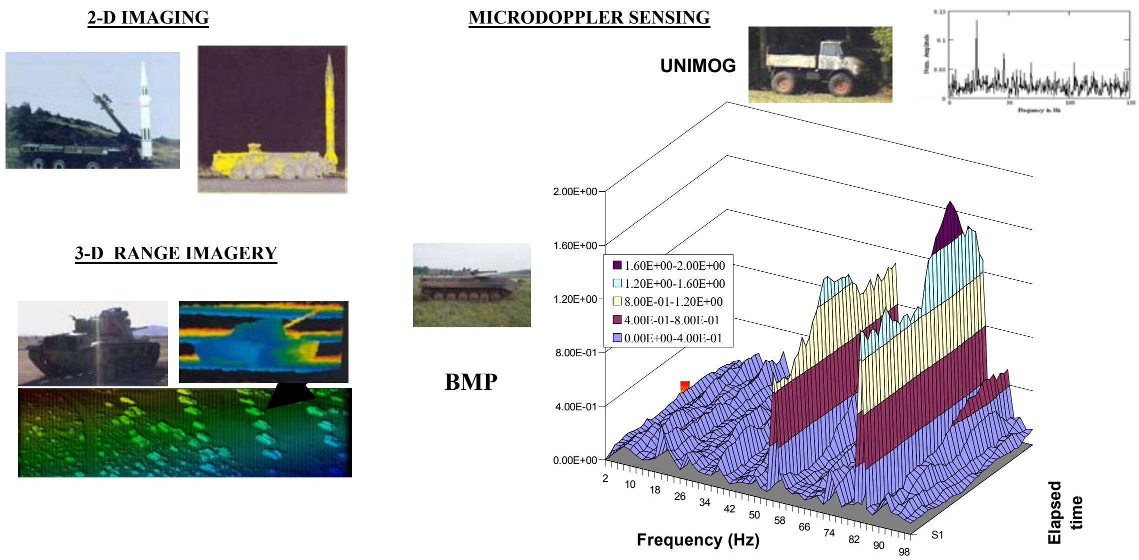


Figure 7: LADAR NCID Options.

Although the RTG-45 member nations have a long involvement with these 3 types of LADAR sensors for NCID, they had never conducted a field trial in the urban environment to allow evaluation of how effective they would be. Under NATO SET sponsorship, RTG-45 conducted a 2-week field trial in a representative urban environment at the Russell Tower facility @ Redstone Arsenal Alabama. The 300 foot tower, figure 8, provided the target aspect encountered by a low flying UAV (as described in figures 5 and 6), a helicopter, or even a high altitude fixed wing platform operating at much longer ranges.

Figure 8: Russell Tower facility @ Redstone Arsenal Alabama.

Although there was still interest in performing NCID of a wide variety of U.S. and foreign military platforms, it was critical for this test to include civilian and commercial vehicles as well. The vehicle target set is shown in figure 9, which included pickup trucks modified with 50 caliber machine guns, decoys, and railroad cars. Another critical element of the Urban environment was hostiles with rifles and shoulder launched weapons so these were included in the target set as well.

Figure 9: Vehicle targets.

A further complication to the trials was the incorporation of camouflage on many of the targets to evaluate their effects on the laser systems. Although the thrust of the testing was evaluation of Eyesafe Imaging LADAR systems, some of the national participants had eye hazardous imaging systems. Since the laser sensors were unaffected by time of day considerations, much of the testing was accomplished at night when the warehouse complex and roads were vacated. 5 NATO nations sent representatives to the trials, and a total of 9 LADAR systems were used to perform the data collections. Some typical scenes from the testing are shown in figure 10.

Figure 10: Test Scenarios from field trial.

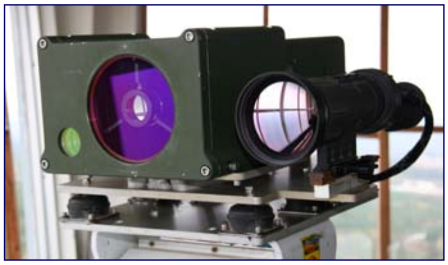
A sampling of the data collected is shown in the following sections.

8.0 2-D FLASH LADAR TEST RESULTS

A 2-D Flash LADAR is used to augment a FLIR's search and recognition capability. It is intended to share the FLIR aperture and provides an automatic magnification (magnification depends on FLIR band relative to the SWIR wavelength) of the target imagery to provide longer-range recognition. For this trial the FLIR operated in the long wavelength infrared so the 2-D FLASH LADAR system produced a 7 x magnification. The 2-D FLASH LADAR uses a deployed laser rangefinder or designator to create a single frame image of the target area. Since the laser system performs this imaging function in the transit time of the laser pulse (no vibration motion occurs in these typically microsecond transit times), it does not require additional stabilization to produce this higher resolution image. In its current realization it still requires an operator to perform the recognition and identification functions by viewing a display, with performance results based on the older Johnson or newer VH50 criterion.

The system test results from the NATO trial shown are provided by the Army Night Vision Directorate at Ft. Belvoir, VA, with their LIVAR 4000 system shown in figure 11. Their system has a fixed field of view that was optimized for imaging targets at ranges > 1 kilometer, where they believe the current passive IR identification capability breaks down.

Front View



Receiver
Reflective Lens
f = 1000 - 1250 mm
dia 6 in
Camera
Intevac TE-EBAPS
NS LM9638 CMOS Imager
gated 1.5 um capability
Integrated HVPS
Gate widths: 100 ns - 10 us
20 Hz frame rate
640x480

Transmitter
Monoblock Laser
λ = 1.5 µm
Energy: 10 mJ
Pulse width: 15 – 20 ns
Flashlamp pumped (1hz)
Beam Expander
variable
single lens/double lens
1.5 - 4 mrad

Figure 11: LIVAR 4000 from U.S. Army NVESD.

So their results are a mixture of partial and complete targets depending on range. The following excerpts, figures 12 to 15, from their test results show the potential for the 2-D approach to improve target identification ranges.

Thursday, October 20, 2005, 7:21 PM
Expander Count Value 120
Gate Delay (m) 389
Gate Width (ns) 1331
First LRF Return (m) 429.32
2nd/Last LRF Return (m) 13210.89
LRF Mode First and Second
image fps 0.5

THERMAL WEAPON SIGHT SINGLE FRAME LIVAR IMAGE

Figure 12: LIVAR 4000 system.

Thursday, October 20, 2005, 7:22 PM
Expander Count Value 120
Gate Delay (m) 389
Gate Width (ns) 1331
First LRF Return (m) 437.57
2nd/Last LRF Return (m) 13359.24
LRF Mode First and Second
image fps 0.5

THERMAL WEAPON SIGHT SINGLE FRAME LIVAR IMAGE

Figure 13: LIVAR 4000 system slide 2.

Tuesday, October 25, 2005, 11:02 AM	
Expander Count Value	47
Gate Delay (m)	5500
Gate Width (ns)	1331
First LRF Return (m)	5563.98
2nd/Last LRF Return (m)	6346.20
LRF Mode	First and Second
image fps	0.8

THERMAL WEAPON SIGHT

SINGLE FRAME LIVAR IMAGE

Figure 14: LIVAR 4000 system slide 3.

Tuesday, October 25, 2005, 10:57 AM	
Expander Count Value	89
Gate Delay (m)	2701
Gate Width (ns)	1331
First LRF Return (m)	2715.31
2nd/Last LRF Return (m)	2870.40
LRF Mode	First and Second
image fps	0.8

THERMAL WEAPON SIGHT

SINGLE FRAME LIVAR IMAGE

Figure 15: LIVAR 4000 system slide 4.

The first generation Laser 2-D imaging systems are rapidly nearing deployment, but there are substantial hurdles which still need to be overcome to automate them for NCID. Instead they are likely to be used at first to extend the viewing range of targets over what can be provided by infrared imaging systems which are the primary day/night target acquisition sensor used by land vehicles and aircraft.

9.0 RATIONALE FOR 3-D OVER 2-D IMAGING LADAR

Although the 2-D FLASH LADAR discussed in the previous section is nearing deployment it still has some drawbacks, which have been overcome with 3-D LADAR imagers. Single frame 2-D images will always be degraded due the nature of the camera (non-uniformity of response), and the laser interaction with the target. A more significant issue is that the successful use of this type of LADAR to discriminate targets from backgrounds is highly dependent on the contrast generated between the target and the background. In figure 16 below an example is shown where the target exhibits little reflectivity difference from the background (e.g. targets that become covered with dust from driving down a road and assume the same reflectivity properties as the road). If instead a 3-D image of the same target is provided, then the range resolution of the sensor can be used to pull the target out of the background.

LADAR 2-DReflectance

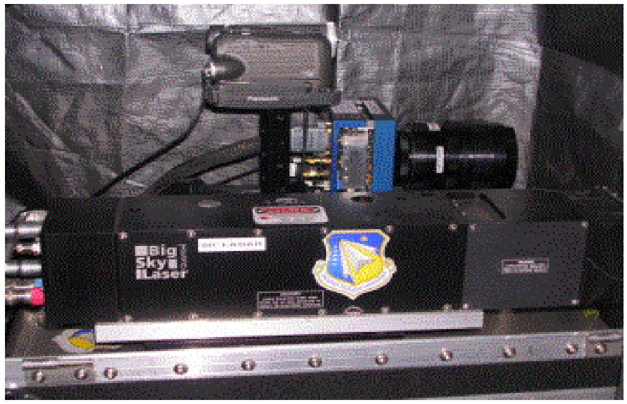
LADAR 3-D Range Fused with Reflectance

Figure 16: LADAR 2-D and 3-D Reflectance.

Not only does the 3-D imagery contain the silhouette information of the 2-D system, but because it has high range resolution for each pixel it actually contains the detailed shape information of the target that can be used to perform automatic target identification as discussed in later sections.

10.0 3-D LADAR USING STARING DETECTOR ARRAYS

Again with the emphasis on using the lasers that are already deployed today and are already planned to be deployed in the future, the Air Force Research Lab at Wright Patterson AFB, Ohio, provided a 3-D FLASH LADAR with a staring detector array (other 3-D LADARs at the trial employed scanners and small linear arrays of detectors). This sensor is shown in figure 17, and uses a variety of modified camera lenses to provide different fields of view and resolutions. The Nd;YAG laser output is coupled to an Optical Parametric Oscillator (OPO) to produce an eyesafe laser output.



C-mount lens adapter on system
75, 100, 100-300, 1200 mm lenses
NdYAG with OPO (l = 1.5 mm)
Diffusers – ½o, 1o, 5o
70 mJ per pulse
Pulse Width = 4 ns

Figure 17: 3-D LADAR using Staring Detector Arrays.

This 3-D FLASH LADAR uses a 128x128 element detector array so that each high range resolution image contains 16,384 pixels. A sample of the imagery from this 3-D system is shown in figure 18. It is the same truck containing men with weapons as shown in the 2-D FLASH LADAR image of figure 13.

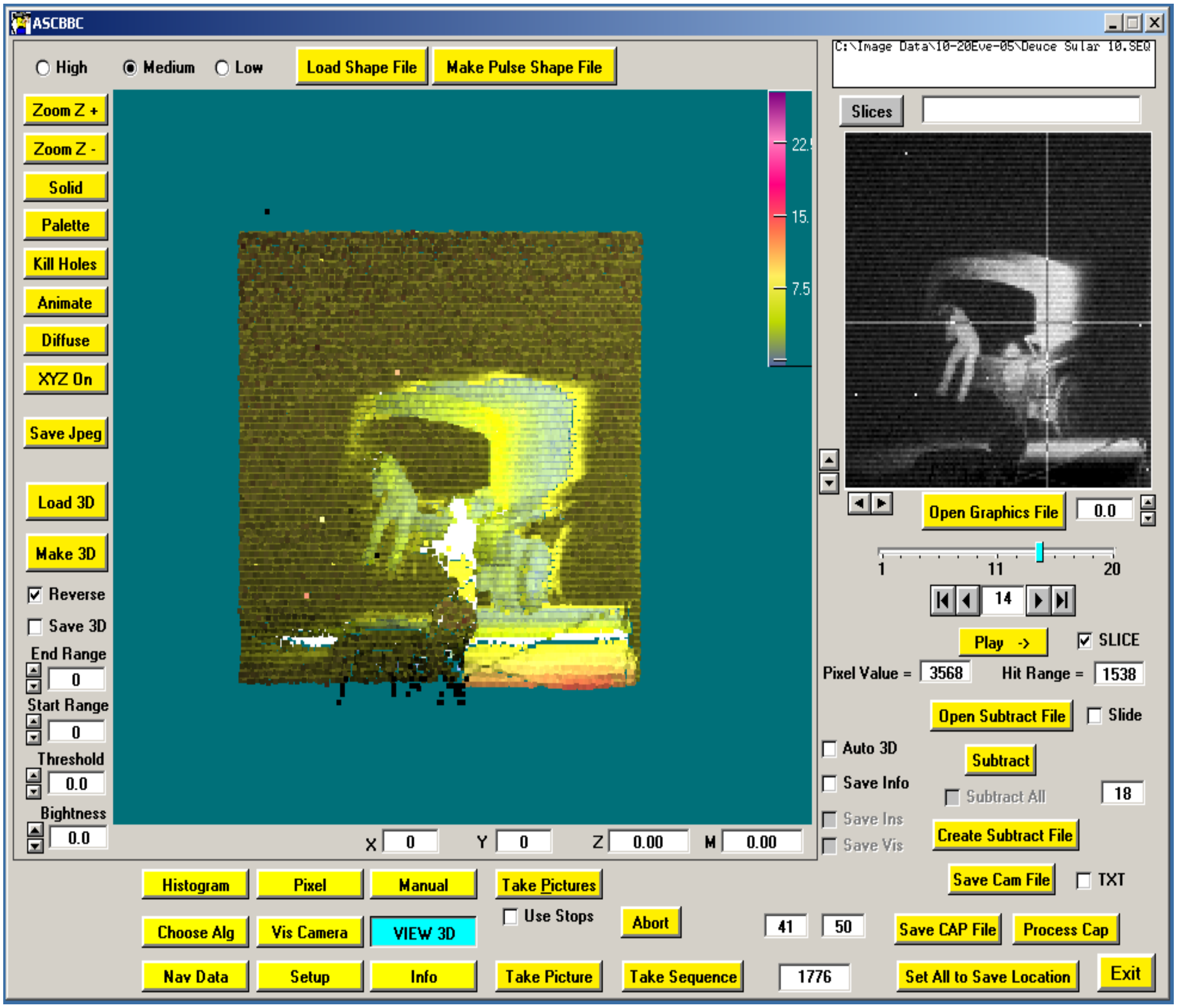


Figure 18: Imagery from 3-D system.

3-D LADAR imagery, because it captures the shape of an object has been shown to produce extremely stable signatures, which have been exploited for automatic target identification. A generic approach to automatic target recognition is shown in figure 19, where raw LADAR imagery is preprocessed to reduce noise, and then compared to stored target databases to produce high confidence identification.

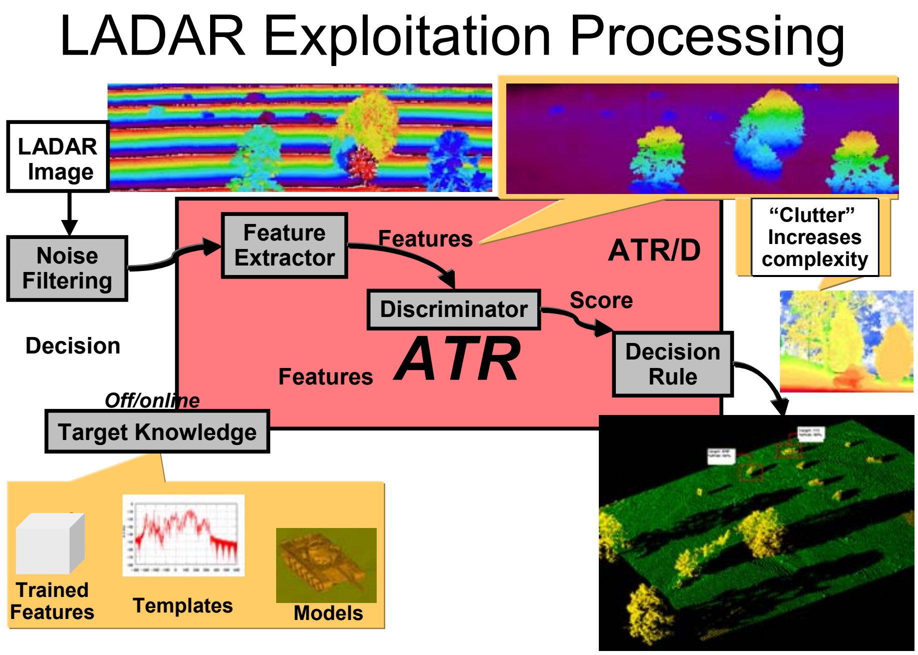


Figure 19: A generic approach to automatic target recognition.

The ATR community has developed a measure for use in evaluating the effectiveness of automatic identification based on pixels on target. Figure 20 shows the current status of the technology, indicating that for land vehicle sized targets about 400 pixels on target are needed for high confidence ID.

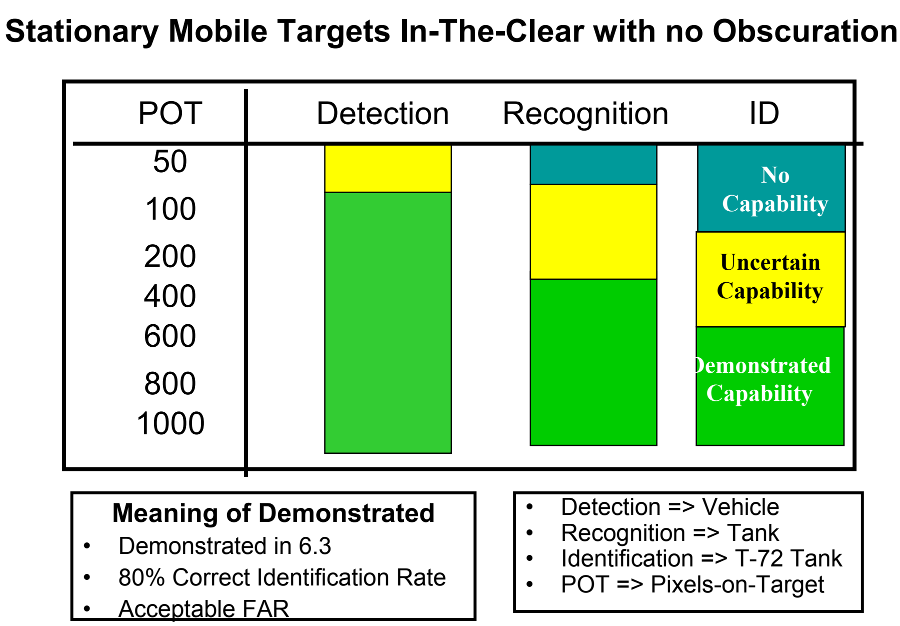


Figure 20: Current LADAR ATR Capabilities.

11.0 VIBRATION SENSING WITH LADAR

Recently the member nations of RTG-45 have been demonstrating laser vibration sensing using technology developed for the telecommunication industry. These are coherent LADAR systems, which are capable of sensing micro-Doppler information from moving surfaces of targets. This vibration information is due to the coupling of the engine energy into the vehicle structure. Although this type of data has been collected by a variety of nations from a variety of vehicles, only recently has the RTG-45 member nations begun to investigate the use of this as a non Line of Sight sensor. So instead of having to view a target directly to obtain its vibration signature, it has been demonstrated that these signatures can be extracted from walls and ground surfaces in the vicinity of the vehicle. In particular a result produced by the German FGAN-FOM organization is shown in figure 21. Here the vehicle of interest is obscured from the sensor by a small building, but the laser vibration signature of the operating vehicle can be detected on the walls of the building and even on the surrounding ground. A similar result in from a longer range is shown in figure 22. The investigation of this phenomenology is still continuing and the potential and limitations of this approach will be the subject of a future report.

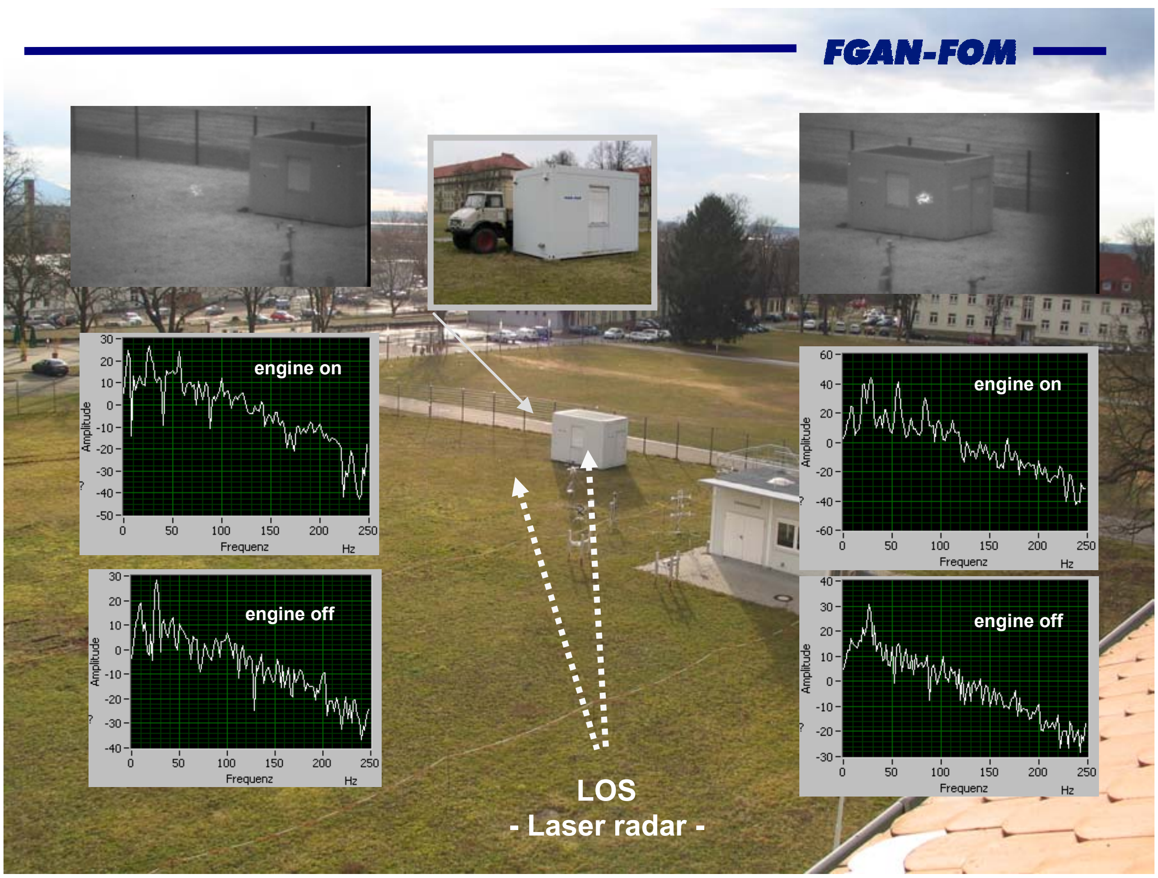


Figure 21: Vibration sensing results.

FGAN-FOM

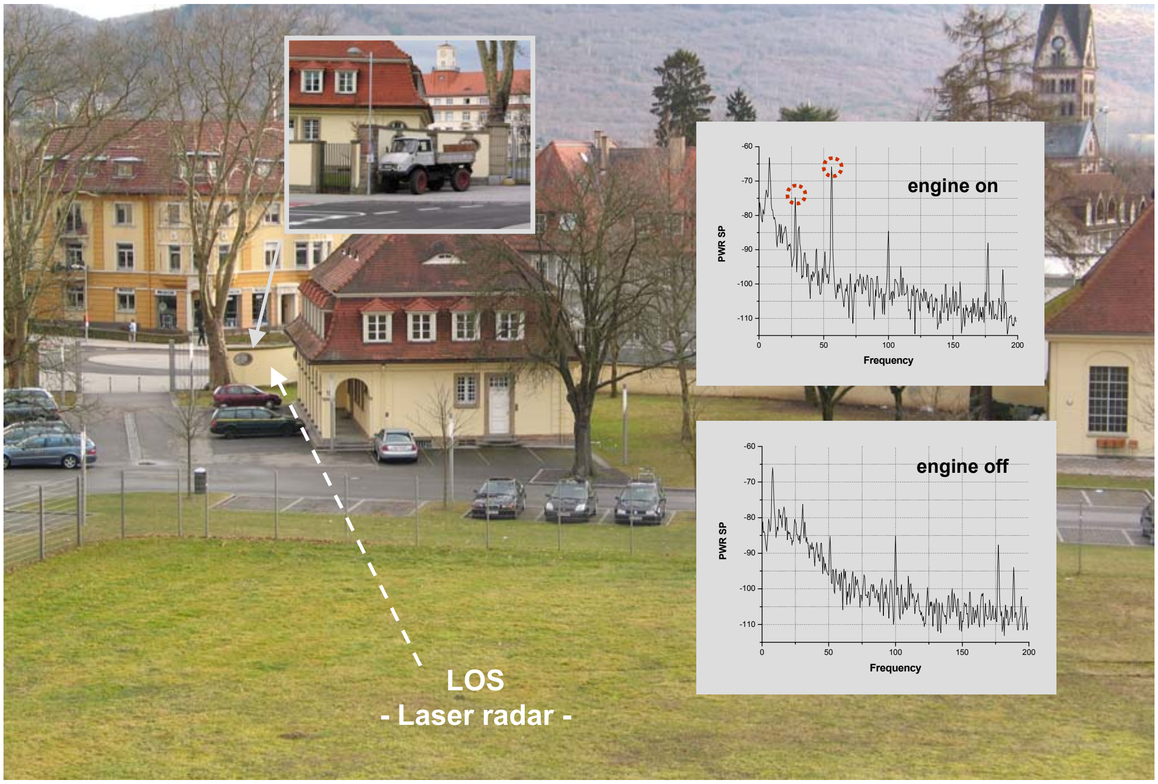
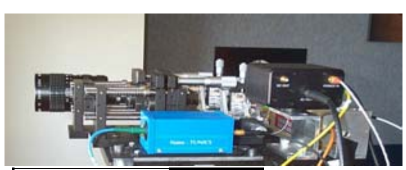


Figure 22: Longer range of vibration sensing results.

An example of this type of eyesafe laser vibration sensor is shown in figure 23. It is based on laser sources (Erbium Fiber lasers), and detectors (InGaAs) developed by the telecommunication industry, and packaged into a LADAR using commercially available fiber optic couplers, and splitters. This system was built at the Swedish FOI laboratories, but at least 4 other NATO nations have produced this class of sensor.

URBAN LADAR NCID
Coherent Laser Sensors
Swedish CW Vibration Sensor



Output laser power	2W
Wavelength	1.569mm
Transmitter aperture	30 mm
Beam divergence (full)	0.12 mrad
Receiver aperture	30 mm
Detector bandwidth	125 MHz

Figure 23: Eyesafe laser vibration sensor.

12.0 SUMMARY AND CONCLUSIONS

NATO through a variety of panels and committees has had a long-term involvement with combat identification intended to produce common systems for coalition forces. Some of these efforts are discussed including the current CID system described in NATO STANAG 4579 and the developmental systems investigated by AC243 TG-11. NATO SET 077 RTG-45 continues to investigate the use of LADARs for a variety of military applications. In particular the application of LADAR techniques to Non-cooperative Combat Identification has been a continuing interest of this group. This report describes a field trial conducted by RTG-45 in an urban environment, where 9 LADAR systems viewed a wide variety of military and commercial vehicles, as well as personnel carrying shoulder launched weapons and rifles. The imagery collected with these LADARs in this urban environment will be used by ATR developers to refine their algorithms to contend with urban issues such as partially obscured targets, mix of military and commercial vehicles, modified civilian vehicles, and personnel with portable weaponry. A subset of the LADAR systems tested can operate with the pulsed laser rangefinders and designators, which are deployed today. These 2-D and 3-D imaging LADARs discussed in this paper are based on small staring detector arrays which can be integrated with small UAV's and helicopters for short range operation or larger fixed wing aircraft for long range operation. In a related effort one of the RTG-45 member nations (Germany) has begun the investigation of Non Line of Sight vibration sensing techniques for identification of completely obscured targets. Some preliminary results from their testing are provided. LADAR has tremendous potential for providing a Non-cooperative Combat Identification capability, which would have considerable benefit in urban environments.