Emerging Opportunities in Optical Sensing and Exploitation

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Sun Tzu wrote: "Know the enemy and know yourself; In a hundred battles you will never be in peril."
 But how can we come to know the enemy?
 I'm here today to say that advanced optical sensing can be a big part of the answer.

The military problems I am talking about are target identification problems.
 As examples, identifying a military vehicle, finding a dismounted soldier, or detecting an improvised explosive device of some unknown design: each is a different kind of target identification problem.
 Another kind of recognition problem is recognizing a friendly unit or a non-combatant as not being a target.
 Within this context of target identification, advanced optical sensing promises a better solution by bringing a better sensor to bear.

What do I mean by "advanced optical sensing?"
 Different combinations of techniques might be applied to different problems, but some of the solutions I see include high resolution imaging, pervasive video, fast shutter video, and most importantly 3-D laser radar.

To snap a great picture of a tough target, we could try to either get a cheap camera in close, or use a much more capable camera from further away.
 If you can get close enough, you don't have to worry about weather and foliage that can obscure your view.
 The tough part is no longer the camera, but rather getting the sensor there, and maneuvering through the trees.
 But if instead we use a really good camera and remain further away, we need a camera which can actually see through obscurants such as weather and foliage.
 But - how can an optical sensor penetrate trees and clouds?

Laser radar offers the possibility to see through some weather, but it is also the perfect tool for peeking around foliage.
 Even a thick forest, some light reaches the ground.
 Looking up on a clear day you will in all probability see many patches of blue sky.
 These holes can be exploited from many viewpoints up above the canopy to build up an excellent 3-D image of what is down on the ground.
 As part of DARPA's participation in Future Combat Systems, this concept has been proven with real hardware and real data.

The Laser Radar system that you see here is one of the Jigsaw sensors.
 We have integrated it onto a helicopter and demonstrated it in the air.
 The 3-dimensional movie now showing is real sensor data.
 First we see the sequence of views collected by the sensor, showing only what's near the ground.
 All the returns are combined here resulting in a dense representation of the surfaces in the scene.
 This 3D model can now be viewed from any angle and at any scale.

Clearly, 3-D sensing with LADAR is going to revolutionize target identification.

So, now that we can obtain 3-D information from sensors, what are we going to do with the information?
 We intend on solving the Target Identification problem.

One way to do target identification is to present the data to an analyst.
 In fact, it is something of a challenge to find the best way to present three dimensional data to an operator staring at a two dimensional monitor with one pair of eyes.

A rotating 3-D block of data can give an operator a feel for the information.

Another approach is to feed the information into an algorithm, to do automatic target recognition.
Indeed, we think 3-D information makes ATR (that is, automatic target recognition) a cinch.
A computer algorithm doesn't have to project the scene into 2-D images.
When a potential target is considered in 3D, scale changes and problems with perspective transformations all disappear, as the 3D laser radar makes direct, accurate measurements of the geometry of the target.
Features like vehicle length, width and height are unambiguous, along with much more, given the high resolution possible.
The recognition of specific parts of targets is possible and so is the converse: the recognition of targets by their sum of parts.

What sort of resolution is possible?
Indeed, what sort of resolution do we need?
In principle an optical sensor can achieve very high spatial resolution, with many systems performing near this theoretical limit.
Sub centimeter resolution appears possible at tactically interesting ranges.
Range resolution is a different story, but at DARPA we have seen example systems with range resolution of a few centimeters, and we believe that finer resolution is possible.

Let's think about what resolution like this enables.
Certainly, we should be able to distinguish between vehicles, even if they are very similar, by finding distinguishing features or parts.
In fact, fingerprinting is possible, that is recognizing specific serial-number vehicles based upon their unique features.
Vehicles could be fingerprinted by battle scars, missing or spare parts attached to the vehicle, manufacturing details, or irregularities.

Another task assisted by millimeter 3-D resolution is battle damage assessment.
If a military vehicle is targeted and hit, how do you know it's dead? Certainly it would help if you could see the bullet hole.
Missing or deflated wheels are easily recognized, or even broken axles can be recognized from wheels that are askew.
BDA is a genuinely hard problem, and 3-D sensing might well be a necessary and sufficient approach.

Fine resolution 3-D sensing, or coherent laser radar sensing, would allow us to measure the vibrations of the skin of a vehicle, a technique known as vibrometry.
Vibrometry can determine if a vehicle is still running, and hence can be another method to assist in BDA.
A laser radar could even use vibrometery against the ground near a concealed target.

The direct measurement of 3D geometry opens up a whole new world of possibilities in geometric change detection.
The 3D geometry measured by a 3D laser radar is invariant to lighting conditions, weather, and soil moisture content.
Small changes, such as leaves that blow in the wind, can be discounted through simple recognition techniques, leaving the possibility to alert only on specific changes, such as the movement of a vehicle, or emplacement of an air defense unit.
We can develop the system to trigger on objects that have been added, or objects that have been subtracted from a scene.
3-D registration techniques can assure us that virtually all else will cancel.

Consider this technique applied to the same scene in "before" and "after" collections, separated by some interval of time.
With resolution of a few inches, we should be able to see the movement of a dismount soldier.
The same soldier might be impossible to see with a 2-D image, due to camouflage, or

the cover of foliage, or insufficient resolution.
But with 3-D change detection, the presence of people where they shouldn't be present is easily discerned.
A bomb by the side of the road, which wasn't there yesterday, stands out like a sore thumb if nothing else has changed.

Now suppose that the before data is archived in a database.
Then, we can perform live change detection in one pass, by calling upon the archive for the before scenes.
The same system could correlate the observed 3D landscape with the archived map, to super-precisely know its location and viewing direction.
The treetops can be measured in realtime, enabling aggressive treetop level flight.
Further, a laser radar is the perfect tool for collision avoidance against wires, towers, and other aircraft.
Anything unexpected stands out in 3D with stark contrast from the background.

I hope I've helped convince you of the huge untapped potential in optical sensing.
The main point is that by using active illumination, we can get 3D information with very high resolution, and that 3D data enables target recognition.
In the future, optical sensing techniques will include vibrometry, spectral sensing, motion detection, advanced change detection techniques, communications, and a host of valuable military surveillance applications.
There are hundreds of terahertz of bandwidth across the visible portion of the electromagnetic spectrum.
However, if you are willing to surrender orders of magnitude of bandwidth potential, you might consider a radio-frequency solution for your sensing needs.
To further discuss the few remaining avenues for exploration in the RF realm I now give you Gerard Titi.
Take it away Ti.