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Teleprompter Script for Dr. Jennifer Ricklin, Program Manager, Strategic Technology Office – The Warfighter Presentations

Seeing Through the Haze

» **JENNIFER RICKLIN:**
Here at DARPA we are pushing the boundaries of imaging sensor performance on the battlefield by working to completely change the current paradigm of sensor operation.

The performance of electro-optical and infrared imaging sensors of all sorts has always been greatly impacted by so-called atmospheric "seeing" conditions.

And this very fact provides the fundamental idea for how we plan to go about doing this:

what if we were to develop imaging sensors with vastly improved operation under adverse weather conditions,
that instead of being limited by the weather, instead exploited the very physics currently limiting their performance to achieve unprecedented resolution.

Let's just reflect on this
for a few minutes.

Clouds, fog,
atmospheric turbulence, smoke, smog,
particulate matter, dust, pollen, and even foliage.

These are all challenges for our sensors.

The term “fog of war” refers to the uncertainty that descends over the battlefield once
fighting begins.

Without adequate surveillance and reconnaissance,
this “fog of war” can begin well before the battle
even starts.

Let’s consider the following questions:

What if we could see through the clouds?...

What if we could see through fog like it wasn’t even there?...

What if
atmospheric turbulence, rather than completely distorting an image, instead led to a resolution several times greater than the diffraction limit?...

What if?

In today’s warfare environment,
and this includes urban and asymmetric threats, being able to see anyone anywhere at any time is critically important.

In the past,
most surveillance and reconnaissance assets were utilized only by the more senior commanders due to the large expense and low density of those assets.

But with the ever advancing innovations and improvements in technology,
we have a unique opportunity to provide surveillance and reconnaissance assets to the wider military audience,
from the strategic level
all the way down to the tactical level.

But… these assets are of kind of limited value if adverse conditions limit their effective use.

That is, if the clouds are
in the way.

Optical imaging has traditionally provided the most detailed information available because of its short wavelength,
and it appears the most natural looking to us human interpreters.

But optical imaging is limited to those occasions when and where conditions are favorable;

namely cloud-free lines of sight, light or no haze... little or no smoke and dust... and low atmospheric turbulence.

Of course there's always radar imaging or millimeter wave imaging but then there's physics, too:

the longer the wavelength, the lower the resolution of the imaging system,
and the more likely other issues such as multipath and specular scattering become a factor.

So why not use physics to our best advantage?

Through control of the signal power and bandwidth,
and through clever,
really clever,
processing techniques, use the properties of the atmosphere to instead increase resolution at optical and infrared frequencies under adverse conditions,
and to increase the range of use under adverse conditions.

So let's talk about a few existing DARPA programs.

The SALTI program (SALTI stands for "Synthetic Aperture Ladar for Tactical Imaging") uses a synthetic aperture, which is a radar imaging technique with a long history of success,
to achieve ultra-high resolution at long ranges.

This ultra-high resolution is made possible because of the shorter optical wavelengths in comparison with longer radar wavelengths.

Last year SALTI applied this approach for the first time to airborne laser radar to create the world's first synthetic aperture ladar images.

This was such a challenging,
difficult problem that many people,
including especially me, thought it would never work.

When I was first given this program my initial thought was "you've got to be kidding me".

Certainly it was worth trying, but how on earth would the performers compensate for the motion of the aircraft,
and the phase distortions induced by the atmosphere?

So imagine the excitement when it not only worked, but it worked gangbusters under a wide range of weather conditions with varying ranges.

Now the fundamental limit of synthetic aperture ladar technology is atmospheric coherence,
which is limited by atmospheric turbulence.

For a given atmospheric condition, there is a range at which the laser wave-front is no longer planar.

When this happens synthetic aperture ladar image processing requires some form of adaptive compensation,
such as autofocus.

Current models have a wide range of predictions as to what this range might be.

In fact we’ve been conducting flight tests to capture data at varying ranges and in various weather conditions to answer these questions.

And of course there is again the issue of clouds.

If you can’t get the imaging laser through the clouds and back again, there will be no image.

The fog of war.

SALTI, and every other electro-optical or infrared imaging system, only works when the clouds don’t get in the way.

When you are close to the ground the major issue is not clouds (although there is always fog to worry about); instead, atmospheric turbulence becomes the boogey man.

But what if.

What if we were able to exploit this atmospheric turbulence-generated micro-lensing phenomenon to create a “synthetic aperture” caused by the turbulence itself?

What if we then built an optical system that was able to capture the information caused by this micro-lensing phenomenon?

This is exactly what we are doing at DARPA
in the Super-Resolution Vision System,
or “SRVS” program, where the goal is to develop, build and field a sniper spotting scope that in the presence of severe turbulence has a resolution more than two times the diffraction limit when severe turbulence exists.

How will we do this?

While most of any instantaneous turbulence-distorted image is severely blurred, small portions of each image actually have higher-than-diffraction-limited resolution due to the atmospheric bending of the light.

If we had a fast-framing camera and were able to pick out these high-resolution pieces and then stitch an image together from these pieces, the result would be an image of outstanding resolution.

This is the goal of the SRVS program:
to develop the necessary algorithms to do this,
and then implement them in a fieldable optical system.

And I can tell you this is not an easy thing to do, but we are working towards this goal and are doing the first field tests of this technology as I speak.

We are also looking at applying some of these techniques to seeing through the air/water interface.

It’s a similar but even more challenging problem.

But how will we ever see through the clouds?

Clouds and fog present perhaps the greatest challenge for any electro-optical or infrared optical system.

Clouds consist of nearly spherical water condensation droplets.

What differentiates clouds is the thickness of the cloud and the size and density of the water droplets.

Electromagnetic scattering from single isolated dielectric spheres has been solved exactly in classical physics as an infinite series expansion- this is called Mie theory.

Most of the scattered energy in clouds is in the near-forward direction, with Mie theory useful in characterizing the wavelength dependence.

The amount of attenuation due to scattering drops rapidly as the wavelength becomes much larger than the droplet radius, which explains why there is very little attenuation at microwave frequencies and below.

But at IR frequencies and above, attenuation is significant.

This is why we humans can’t see through clouds but radar can.

Just as we are showing with SRVS and turbulence that it is possible to exploit the physical properties of the atmosphere to our best advantage, we should now begin to examine if the same can be done with clouds.

Why not?

Processing is cheap.

Algorithms and approaches that would have been impossible to implement even
a few years ago now offer little if any challenge whatsoever.

We “just” need to know the right algorithms and right techniques to implement.

And this defines the challenge.

First we need to well understand and be able to characterize to an adequate level of fidelity the propagation media --
in this case a cloud --
and the physical processes involved in light at optical frequencies --
in this case a laser --
as it interacts with the propagation medium.

One possible solution is to just develop higher power laser illumination sources so that our systems can tolerate the losses as they propagate through clouds and fog.

But the more constructive solution would be to develop waveforms with temporal and spectral characteristics that can isolate and preserve the information that distinguishes target returns from cloud returns.

Finally, what is most needed and what may hold the most promise is to develop signal processing techniques that work to optimize the information in the signal-carrying laser beam.

Let’s think for a moment about this.

Many current electro-optical and infrared systems are passive;
that is, images are produced from the scattered sunlight.

This is how our eyes and conventional cameras work.

In a passive system,
any reflections from targets that manage to penetrate clouds or fog arrive at the same time as those scattered from it.

An active system,
on the other hand,
is illuminated by pulses of light that can be spaced so that reflections from the target arrive at different times
than those from the intervening media.

This offers a key parameter that might be exploited, since one of the advantages of an active system is the ability to control the power and waveform.

In developing new sensors such as SALTI, the Strategic Technology Office of DARPA recognizes that,
while the use of infra-red and optical frequencies offers significant advantages over microwave radar frequencies,
they also have the disadvantage of reduced capability in clouds, haze, and atmospheric turbulence.

There is much left to be explored that may offer the potential key to mitigating and eventually overcoming these disadvantages.

I’ve offered here the example of SRVS,
which actually uses atmospheric turbulence to its advantage through the simple technique of a fast camera coupled with sophisticated algorithms in order to achieve unprecedented resolution.

And then there’s
“ballistic photons”.

Another phenomenon that has been proposed in the literature but not yet exploited is the fact that some photons pass through clouds without experiencing any interaction with cloud droplets, or through haze without interacting
with the particulates.

This is a purely
statistical phenomenon, and the number of such “ballistic” photons decreases exponentially with distance.

Also the spectrum of ballistic photons is skewed in favor of
lower frequencies
(or longer wavelengths) due to the same phenomenon that causes sunsets to be red.

But this phenomenon is worth examining more closely.

And if we look,
other equally intriguing possibilities may become apparent while we’re busy looking.

And this defines the challenge ahead of us.

We encourage your ideas on how to understand the physics of “seeing through the haze” so we can perhaps exploit the very physics defining this problem.

This would turn what is currently a fixed and
well-known limitation -- that infrared and visible frequency wavelengths do not exactly penetrate well through clouds --
into an advantage.

In short, to forever change the meaning of “fog of war” to instead mean “I can see the battlefield”.

Thank you.

Now, to move from seeing the battlefied to seeing the sniper... let me introduce my colleague
Deepak Varshneya.