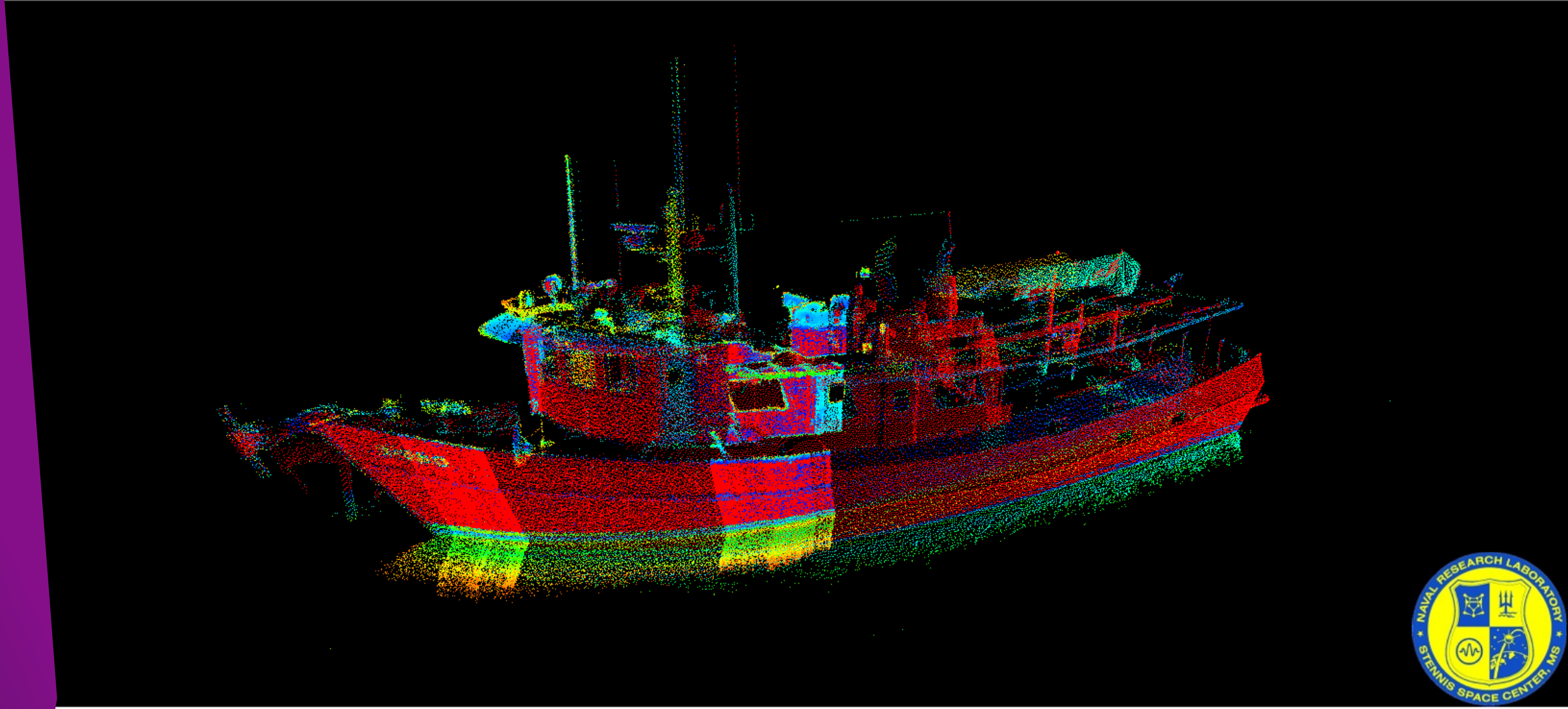

Challenges and Mitigations in Multi-modal Perception Systems for Unmanned Vessels

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Public Release Approval: 20-leidos-0107-21313

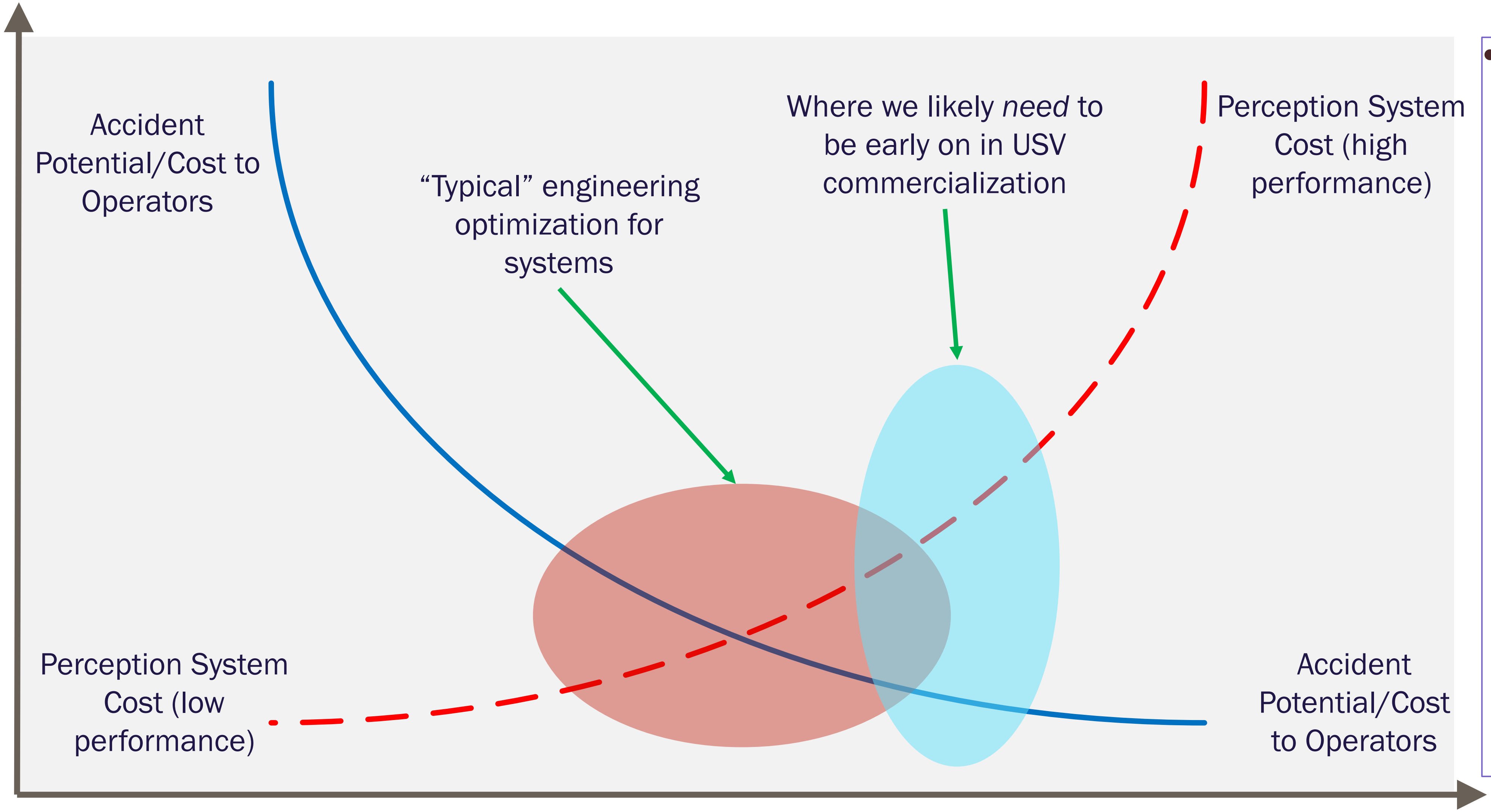
Problem Statement

- In order to be accepted by the international community as “safe”, unmanned surface vessels must demonstrate the ability to perceive or “see” their surroundings in all weather conditions and environments from close aboard to radar range.
- Failure to achieve this performance will result in dire consequences:
  - Accidents and potential fatalities (human and *marine mammal*)
  - Inability to secure government authority to operate
  - Marginalization of the potential value of autonomous systems to commercial and government end users
  - High cost of insurance

U.S. Navy Image 170711-N-VA840-002

Photo Courtesy NOAA Marine Fisheries: Hawaiian Islands Humpback Whale National Marine Sanctuary, Ed Lyman

Engineering Space for USV Perception Systems



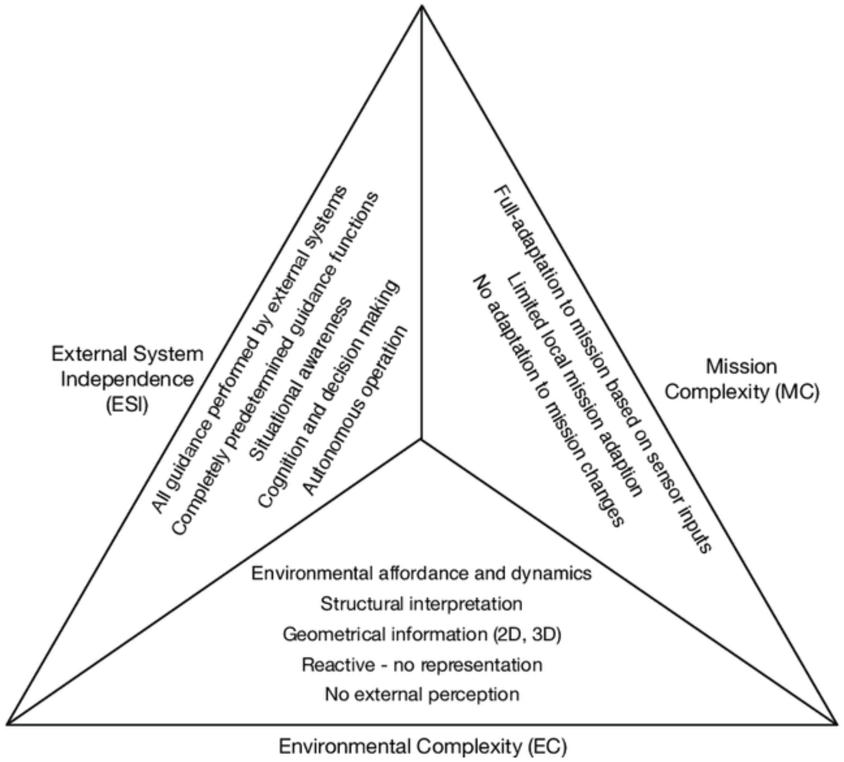
- **Why?**
  - We need to focus on protecting lives and mitgating the likelihood of major incidents/loss
  - We need time to learn how to optimize while still allowing us to operate
  - We need unified standards for perception and World Model performance – stay conservative until that eventualizes

Autonomy Levels for Unmanned Systems (ALFUS) – <u>Doesn't Apply</u>

	reference metrics summaries			ALFUS Levels
reference levels:	**MC**	**EC**	**HI**	**User-defined levels using metrics summaries to the left**
10	highest adaptation, decision space, team of teams collaborative missions; fully real-time planning; omniscient, highest level fidelity SA; human level performance	lowest solution/possibility ratio: lowest margin for error, understandability; highest level of dynamics, variation, risks, uncertainty, mechanical constraints*	performing on its own and approaching zero human interaction, negotiating with appropriate individuals	
9	high adaptation, decision space, team collaborative missions/tasks; high real-time planning; strategic level, high fidelity SA	low solution/possibility ratio, understandability highly dynamic, complex, adversarial high risks, uncertainty, constraints*	UMS informs humans; human provides strategic goals, interacting time between 6 % and 35 %;	
8				
7				
6	limited adaptation, decision space, vehicle tasking; limited real-time planning; tactical level, mid fidelity SA	mid solution/possibility ratio, understandability dynamic, simple mid risks, uncertainty, constraints*	human approves decisions, provides tactical goals, interacting time between 36 % and 65 %	
5				
4				
3	subsystem tasks/skills; internal, low fidelity SA	high solution/possibility ratio, understandability static, simple low risks, uncertainty, constraints*	human decides, provides waypoints, interacting time between 66 % & 95 %	
2				
1				
0	simplest, binary tasks	static, simple	remote control	

MC = Mission Complexity
EC = Environmental Complexity
HI = Human Interaction

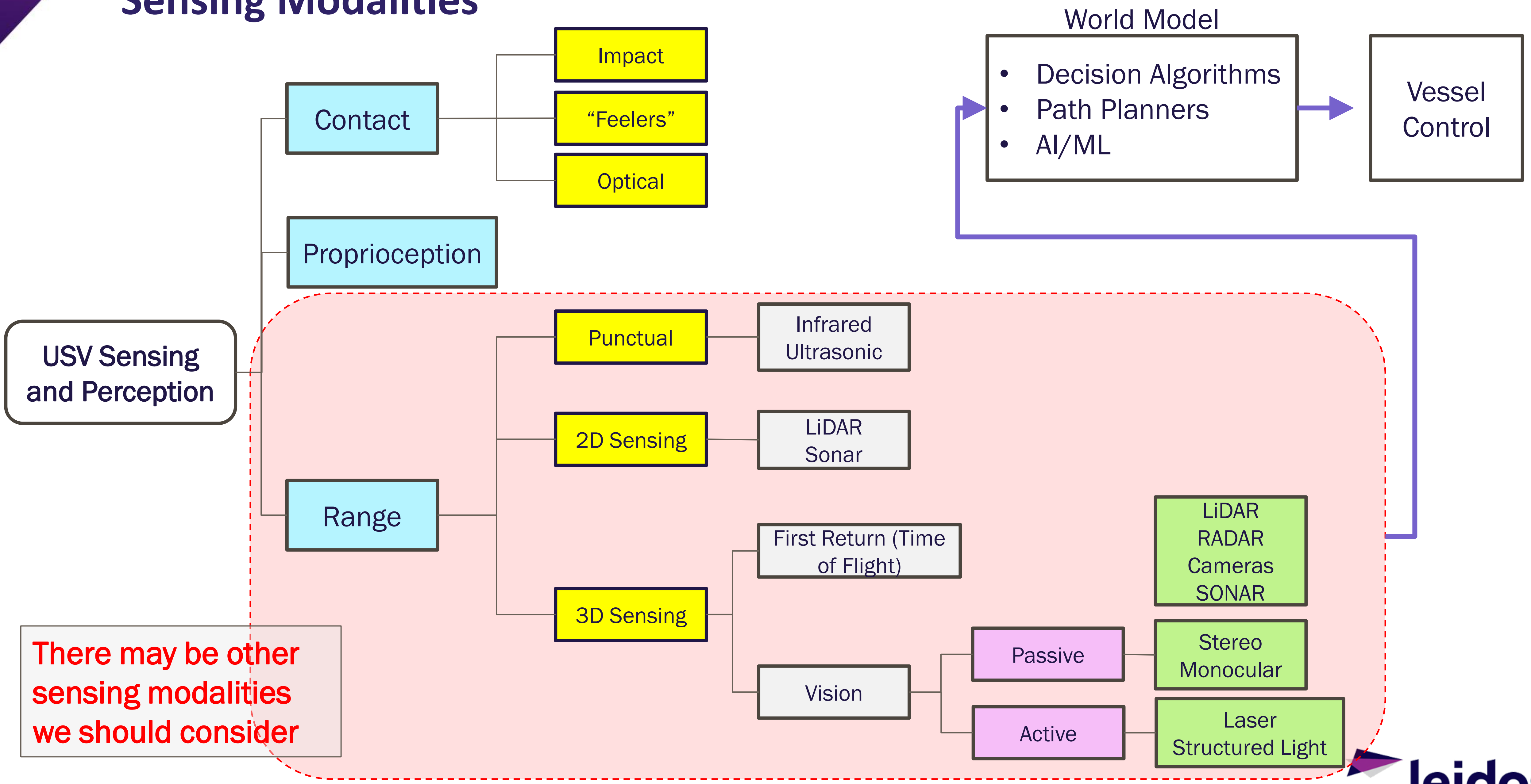
SA = Situational Awareness
UMS = Unmanned System



Sensing/Perception should be an independent issue from levels of autonomy.
Why? Risk and repercussions.

- ALFUS is a framework set up by working group and formalized by the U.S. National Institute for Standards and Technology (NIST)
- NIST Special Publication 1011-I-2.0
- Autonomy levels DO NOT address the basic sensing and perception issue – arguable that the same standard applies at some level across the board
- Different way of thinking about this problem

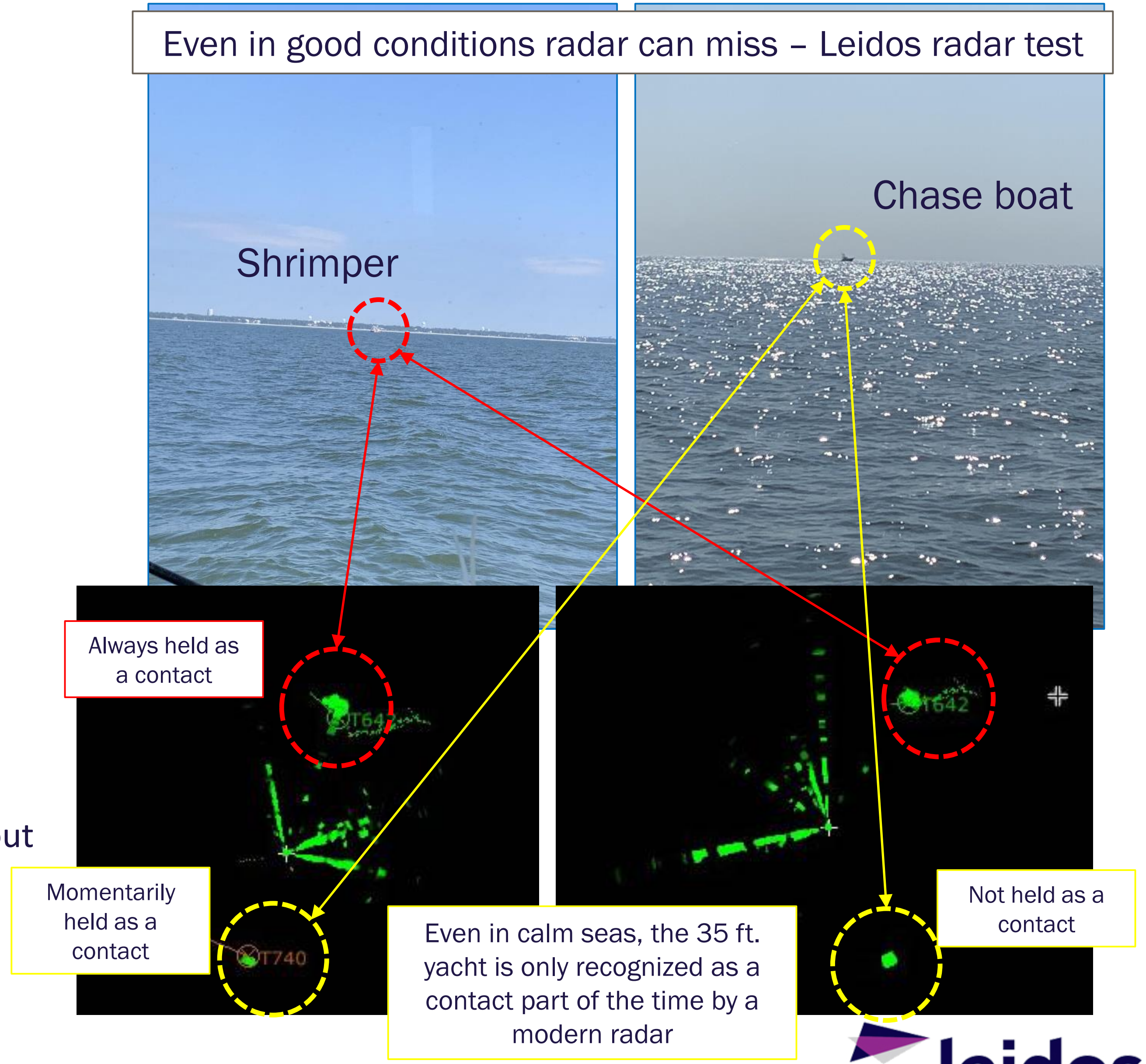
Sensing Modalities



There may be other sensing modalities we should consider

Current Methodologies for Sensing - RADAR

- **RADAR**
  - PROS
    - Most widely used situational awareness sensor
    - Very effective against larger targets in calmer sea states
    - Good COTS algorithms for auto-track
    - Relatively inexpensive
  - CONS
    - Does not perform well in clutter
      - Rain
      - High sea state
      - Dense target environments
    - Can be very poor in the near field
    - Subject to unintentional or intentional spoofing
    - Largely ineffective against broached marine mammals
    - Poor at detecting very small targets (perhaps most worrisome due to nature of small targets – boaters without similar systems)
- **Autonomous vessels MUST have multiple sensors**



Current Methodologies for Sensing – Optical (Visible/IR)

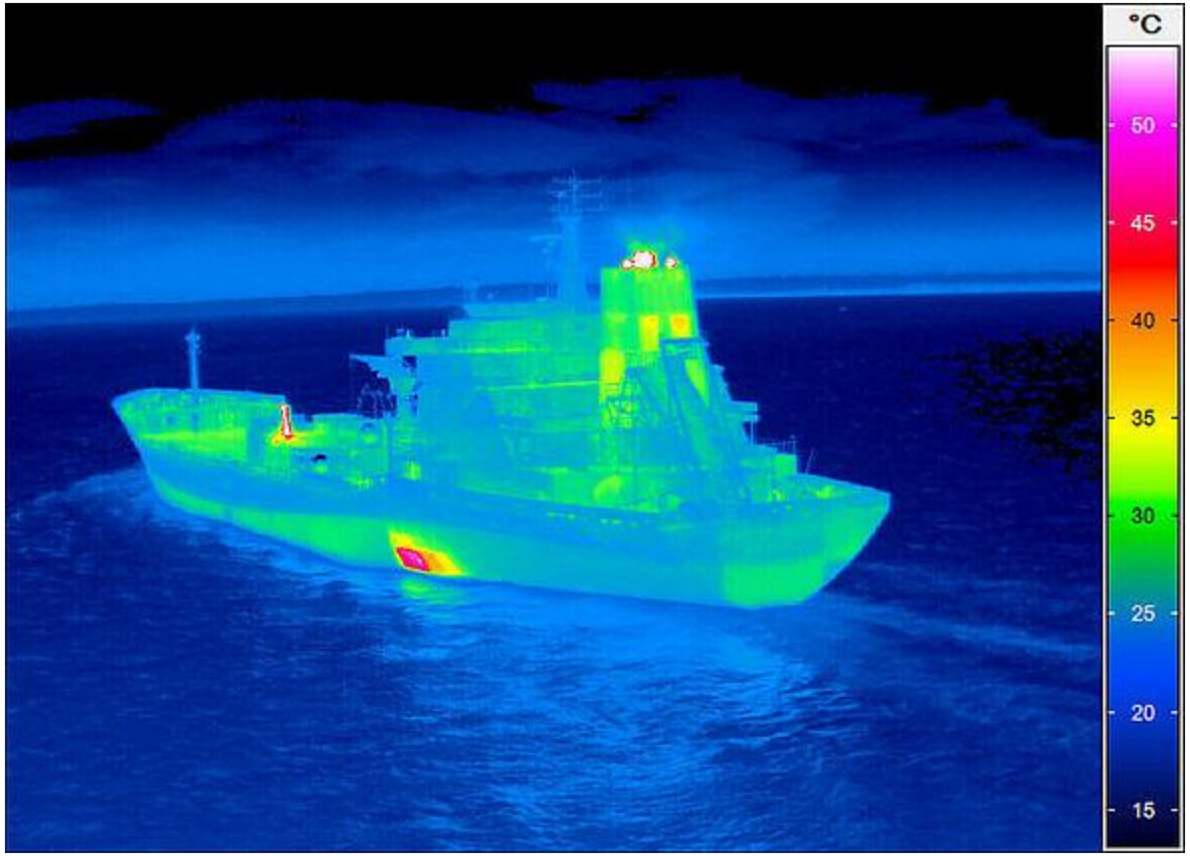
U.S. Navy image 160310-N-WI626-010

- **Optical in the form of visible and IR cameras has great potential**
  - PROS
    - Very high resolution
    - Humans "understand" optical – so processing into autonomous algorithms is logical for humans
    - Relatively inexpensive cameras (but better performing systems can be very expensive)
  - CONS
    - Greatly impacted by weather
    - Some processing approaches may result in high false alarm rates

U.S.Navy image 030427-0-0000B-002

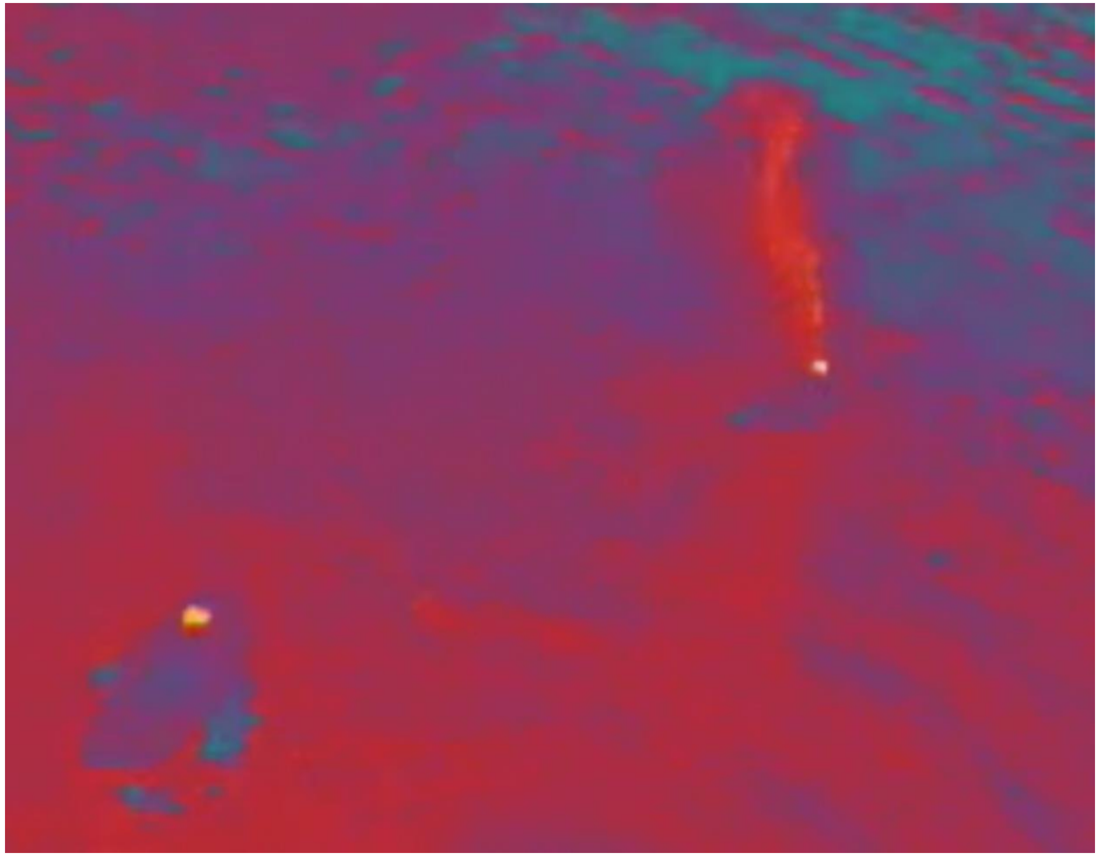
Sometimes Visual and IR Work Well, Other Times….

Could this image be enhanced with artificial intelligence/machine learning?



Ship in this image would be easily exploited in the World Model

Image courtesy InfraTec



Marine mammal in this image is almost lost

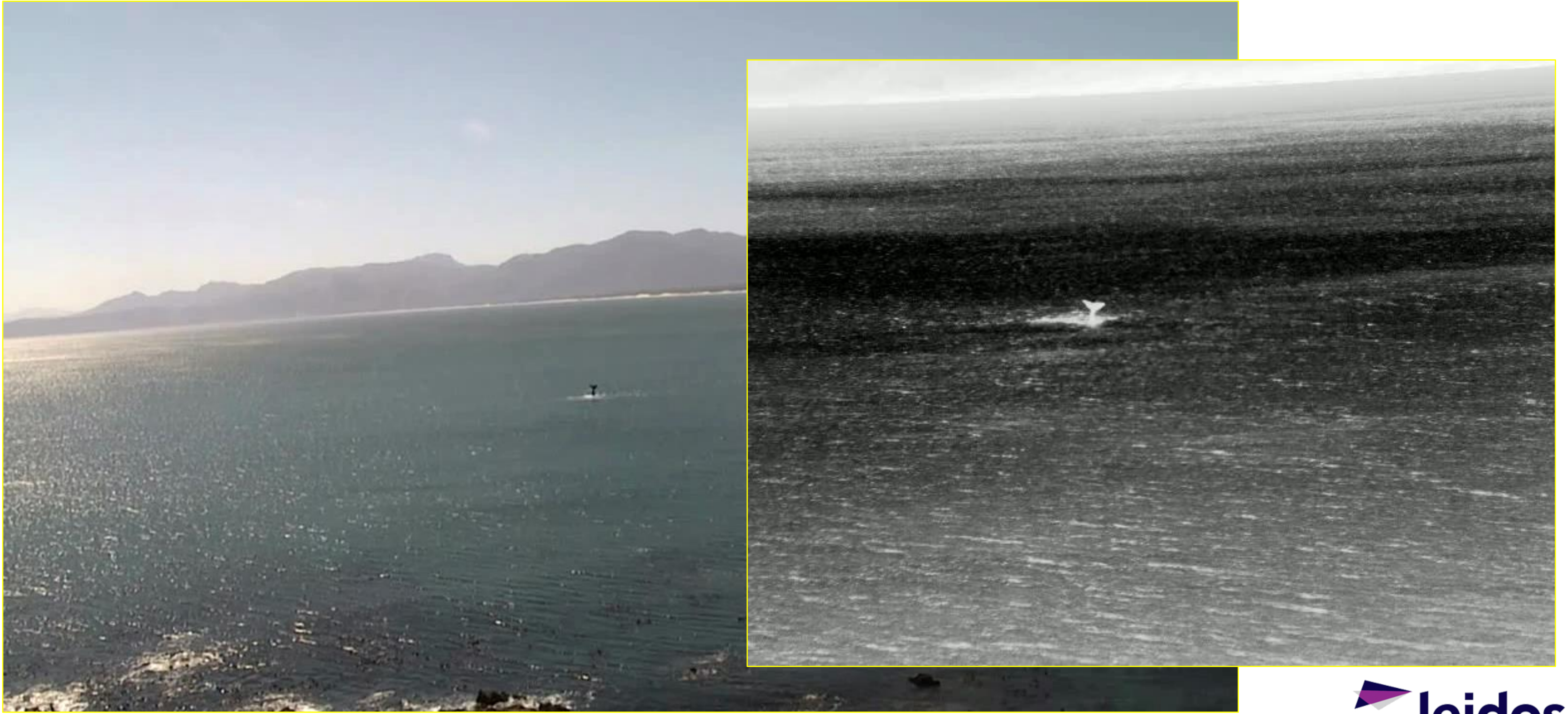
Image courtesy Ocean Alliance Whale Conservation

Whale Breaching on Visual and IR Images

Images taken by and used with permission of Mr. Sam Nichols, Seiche LLC

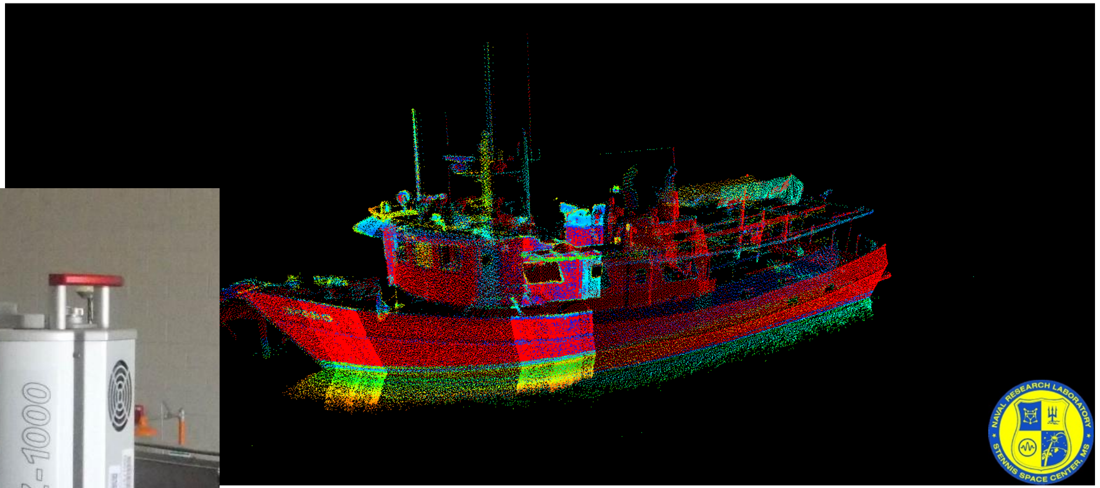
Whale Flap on Visual and IR Images

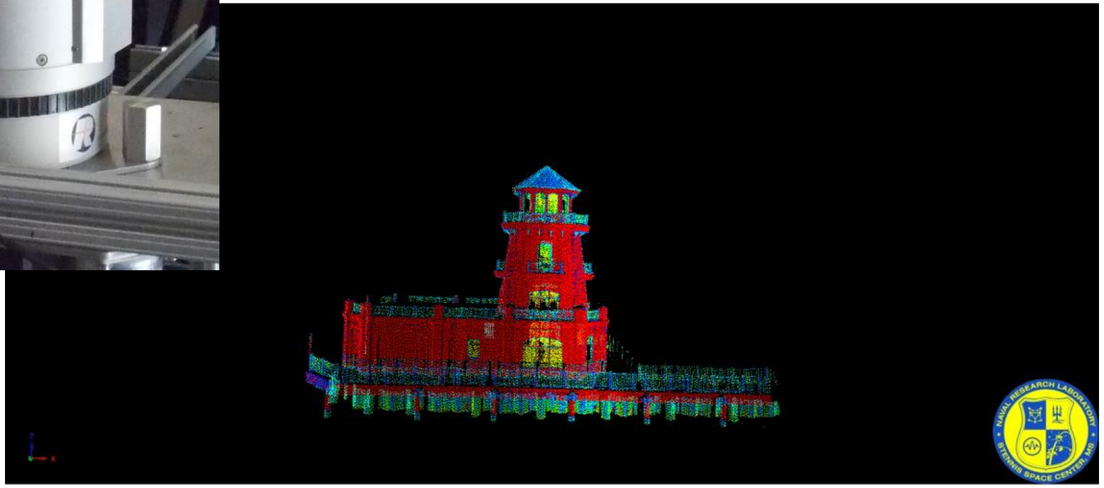
Images taken by and used with permission of Mr. Sam Nichols, Seiche LLC



Current Methodologies for Sensing – Optical (LIDAR)

- **LIDAR**
  - PROS
    - Very high resolving capability
    - Excellent for generating point clouds of data against which processing can be applied
    - Adequate update rate for most USV applications
    - Good near field sensing
  - CONS
    - Equipment can be expensive
    - Limited range (~1000m maximum)
    - Update rate of some systems may not be adequate for high speed vessel applications
    - Affected by high sea states and weather (rain)





Images provided courtesy of the Naval Research Laboratory, Stennis Space Center, MS

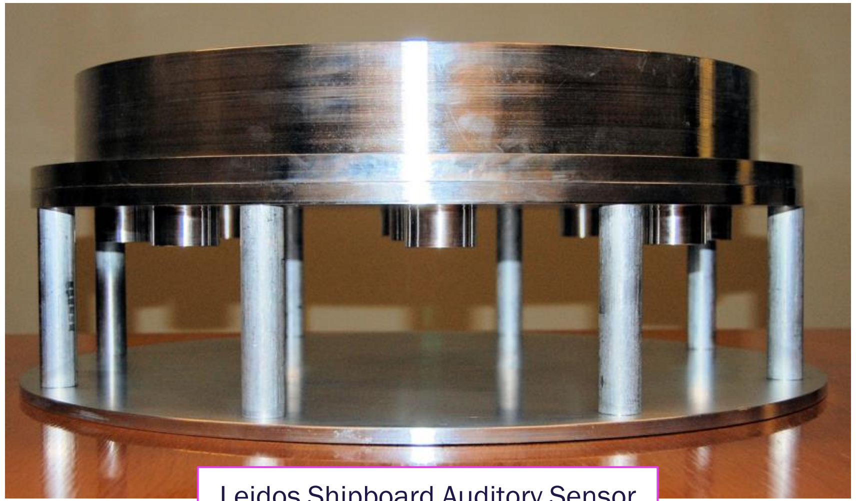
LIDAR IMAGING DEMONSTRATION

Video used with permission of the Naval Research Laboratory, Stennis Space Center, MS

Emerging Technologies as Applied to USVs

Emerging Technologies – Airborne Acoustic

- Airborne Acoustics is on the Way
  - My opinion is that airborne acoustics will eventually be mandatory for large autonomous vessels operating in waterways and on the high sea. COLREGS Rule 35 requires the use of sounds in certain situations, and implies the ability to HEAR those sounds.
  - Given the advent of acoustic recognition algorithms to hear and recognize music, it is not a stretch to believe this will be achievable in the near term. Many companies, including Leidos, are working on acoustic recognition of sounds from vessels at sea.



Leidos Shipboard Auditory Sensor
U.S. Patent US20160221660A1

Pros:
- Relatively low-cost hardware
- Does not take significant space

Cons:
- Affected by ambient noise
- Some potentially difficult installation issues

For gongs, whistles, etc, do we need detection and classification capability?

Emerging Technologies – Ocean Acoustics

- Ocean acoustics could serve multiple purposes as applied to USVs:
  - Detection of vessels when other means are obscured
  - Detection of marine mammals in some cases
  - Potential detection of shoals (breaking waves)
- Implementation could vary greatly depending the size of the vessel and acceptable cost:
  - Hull-mounted hydrophones or arrays
  - Towed arrays

Images of Kingclip sonar courtesy of Applied Acoustic Concepts (AAC)

Pros:

- Known science and signal processing
- Relatively low cost

Cons:

- Ambient noise reduces efficacy
- High traffic areas present discrimination issues

Image of KraitArray towed array courtesy of SEA

Where Does That Leave Us?

- Existing sensor solutions for USVs simply do not provide the probability of detection of vessels (particularly small ones) and hazards consistent with low-risk operation of USVs in all conditions.
  - *Very small vessels (<14m?, <300 tons? – needs to be decided) may be provided some relief from expensive sensing/perception systems*
- Autonomous vessels have the “brain power” to handle these issues IF sufficient perception capability is afforded them.
  - *Reiterating that sensing is the tough problem – not autonomy*
- Governments and commercial insurers cannot afford incidents where loss of life or damage to other vessels occurs.
  - *One incident overcomes many positive developments*
- Potential marine mammal impact cannot be overstated and will increasingly become more prominent in the public eye.

How Do We Make Progress?

- **As difficult as it may seem, we likely need standards of performance for perception systems:**
  - Condition-based:
    - *Example*: 95% Probability of Detection (POD) in SS0, 50% in SS5, etc., using radar against a 10 square meter radar cross section.
    - *Example*: For near field sensing and perception, vessels larger than 300 tons must have optical detection means for ranges inside 1000 yards. These systems must detect, with a 95% POD, any vessel within 500 yards in SS3.
    - Type approval consistent standards of testing – all organizations follow the same approval standards.
    - Let science be the guide for what the standards are – they must be reasonably achievable both technologically and financially.
    - Not the same standard for all vessels –larger vessels should bear the burden of the highest performing systems (and therefore cost).
- **We need true sensor fusion and AI/ML applied to sensing and the world model:**
  - We need more out of sensors
  - The sum needs to be more than the individual parts – how do we maximize utility?

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Thank You