MITMECHE

MIT 2.S01 Introduction to Autonomous Underwater Vehicles

Lecture 4: Introduction to Software Subsystems of an AUV

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MIT Sea Grant AUV Lab

MIT Marine Autonomy Lab

Sense, compute, actuate and repeat

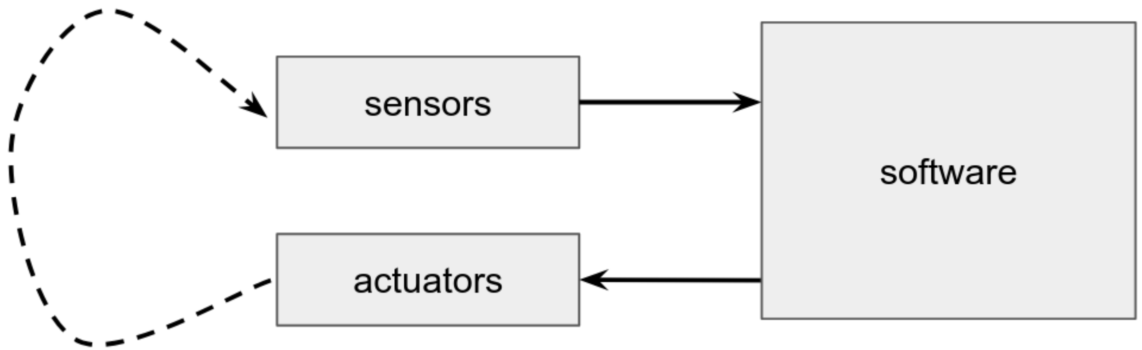
- Recall the sense–plan–act loop we discussed last week.
- This week, we will explore it further through an example mission

Sensors:
- External pressure sensor (measures vehicle depth))
- AHRS (measures roll, pitch & heading)
- GPS (measures latitude and longitude when at surface)

Software:

???

Actuators:
- Control surfaces
- Main propulsion thruster



Searching for an airplane wreckage

Sensors:

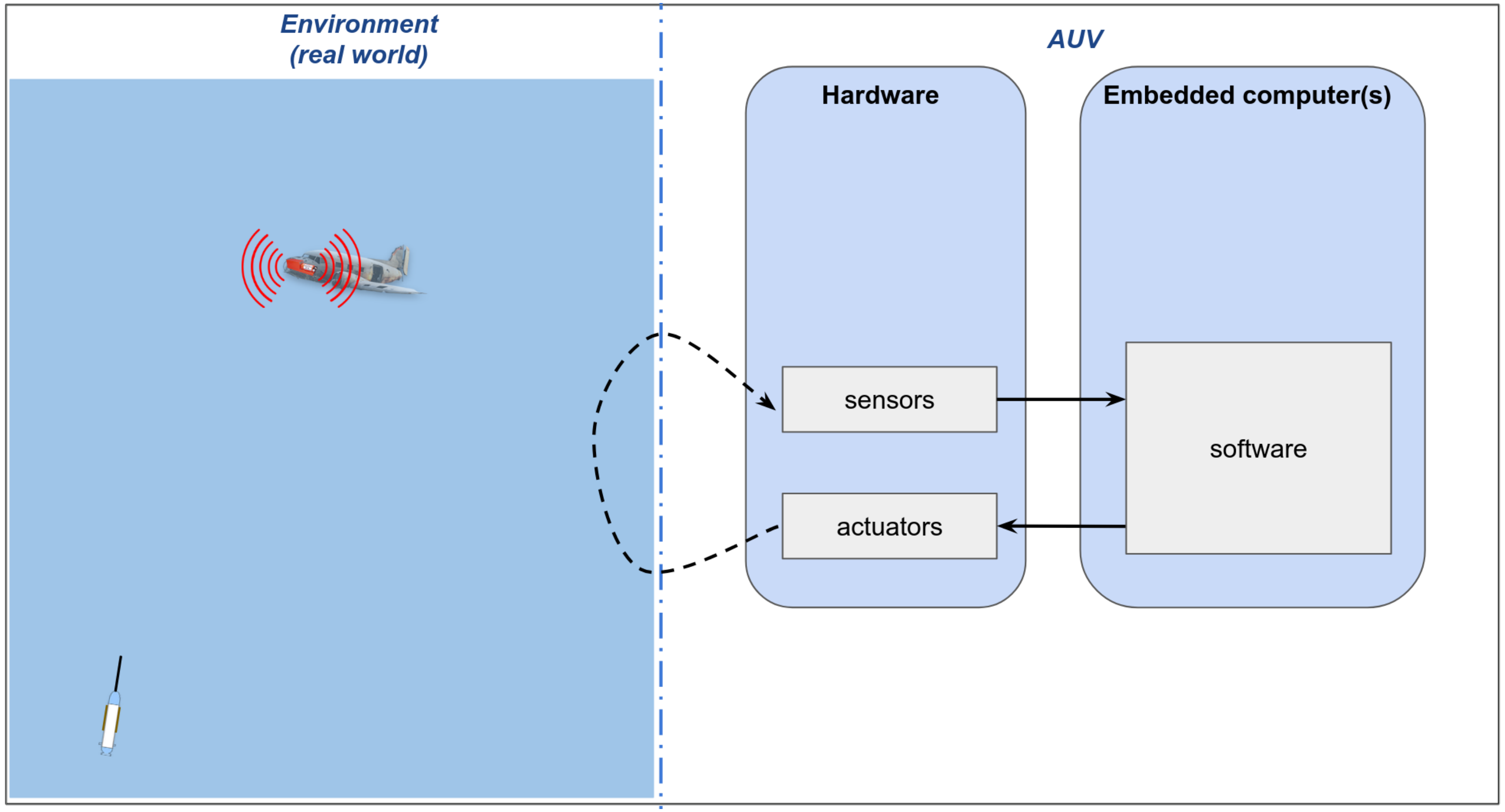
Navigation Sensors
- Depth sensor
- AHRS (measures roll, pitch & heading)
- GPS (measures latitude and longitude when at surface)

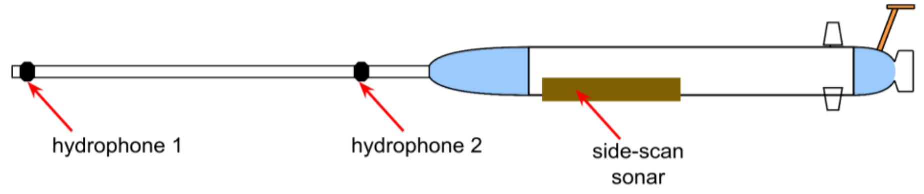
Payload Sensors:
- Side-scan sonar (a payload sensor)
- Nose-mounted array with two hydrophones (a payload sensor)

Software:

???

Actuators:
- Control surfaces
- Main propulsion thruster

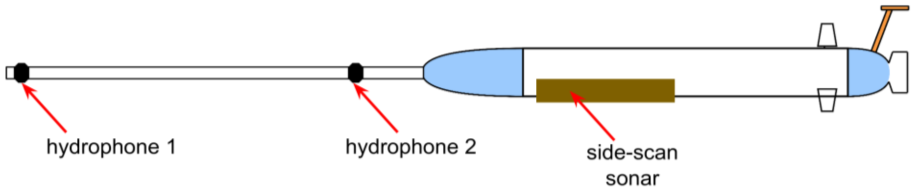




The AUV is extended with two payload sensors:
i. A side-scan sonar
ii. A two-element rigid hydrophone array

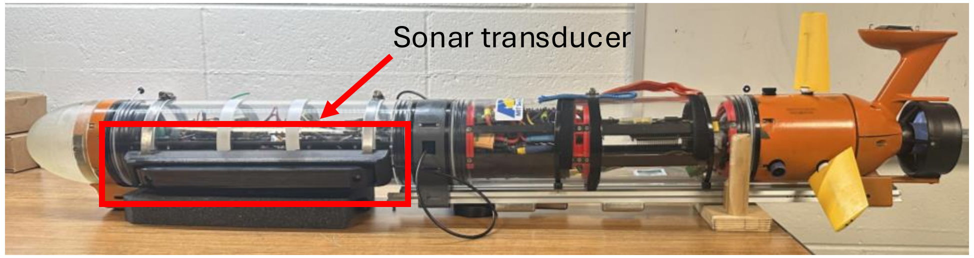
Side-scan sonar

- A side-scan sonar is an active acoustic sensor that uses reflection of an acoustic signal to create images of the seafloor.
- It transmits acoustic signals outward to the sides of the vehicle and listens for the echoes that return.
- By measuring the strength and timing of those echoes, it reveals the texture, shape, and features of the bottom.
- Especially useful when the water is too dark or murky for cameras to see clearly.
- It is often used to map the seafloor, locate objects, and identify features such as wrecks and debris.
- Frequency can range from around 100 kHz up to 2 MHz.
- Our vehicle should maintain a constant altitude to with minimal roll and pitch variations to capture a good image.

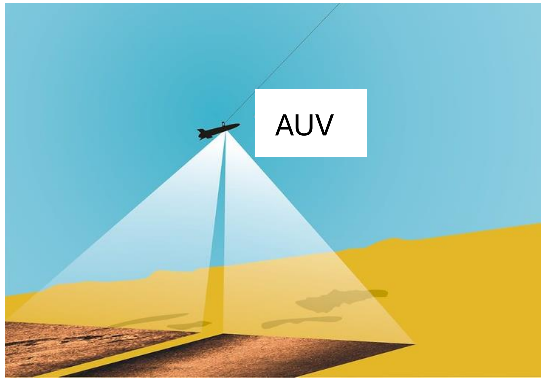


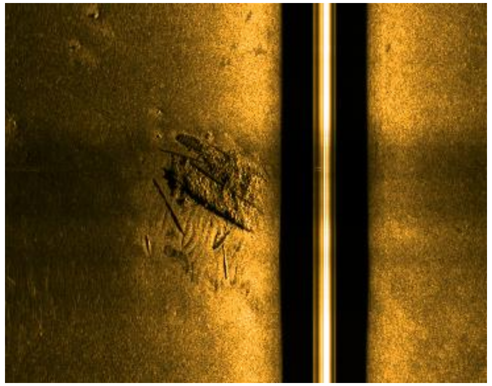
The AUV is extended with two payload sensors:

i. A side-scan sonar
ii. A two-element rigid hydrophone array



Base SeaBeaver + side-scan sonar payload
By University of Delaware

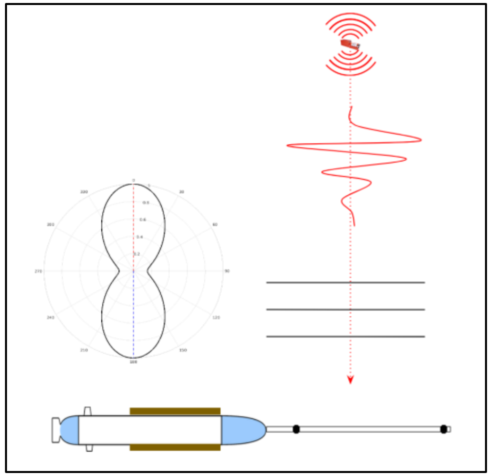


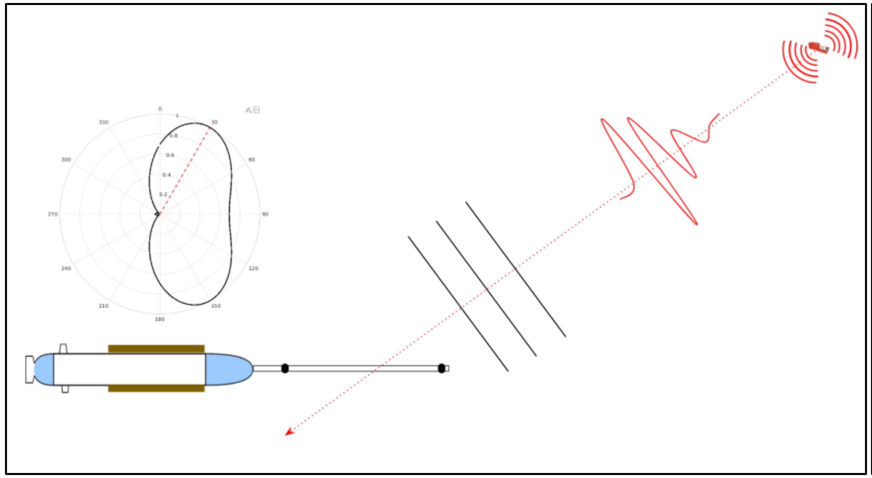


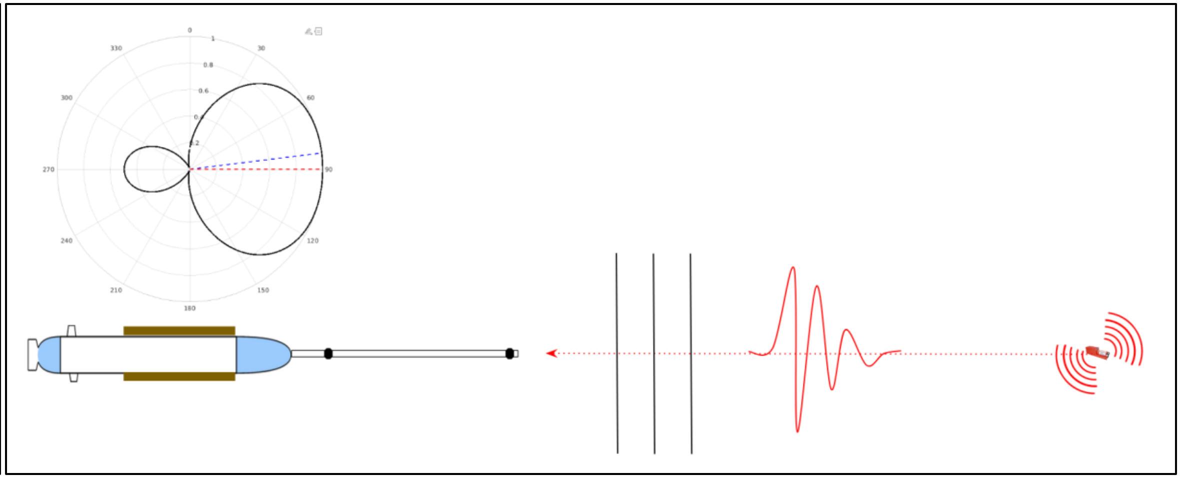
Rigid hydrophone array

(a highly simplified example presented for the purposes of this discussion)

- The two hydrophones mounted on the nose cone measure the acoustic chirp transmitted by the pinger.
- The chirp from the pinger reaches the two hydrophones at slightly different times, depending on the bearing of the pinger relative to the vehicle.
- By comparing the phase difference between the signals received at the two hydrophones, we can beamform and estimate the direction of arrival of the signal.
- Because this is a simple linear array, the estimate has a left-right ambiguity.
- The vehicle's autonomy system should maneuver the vehicle such that the sensing subsystems can resolve this ambiguity.



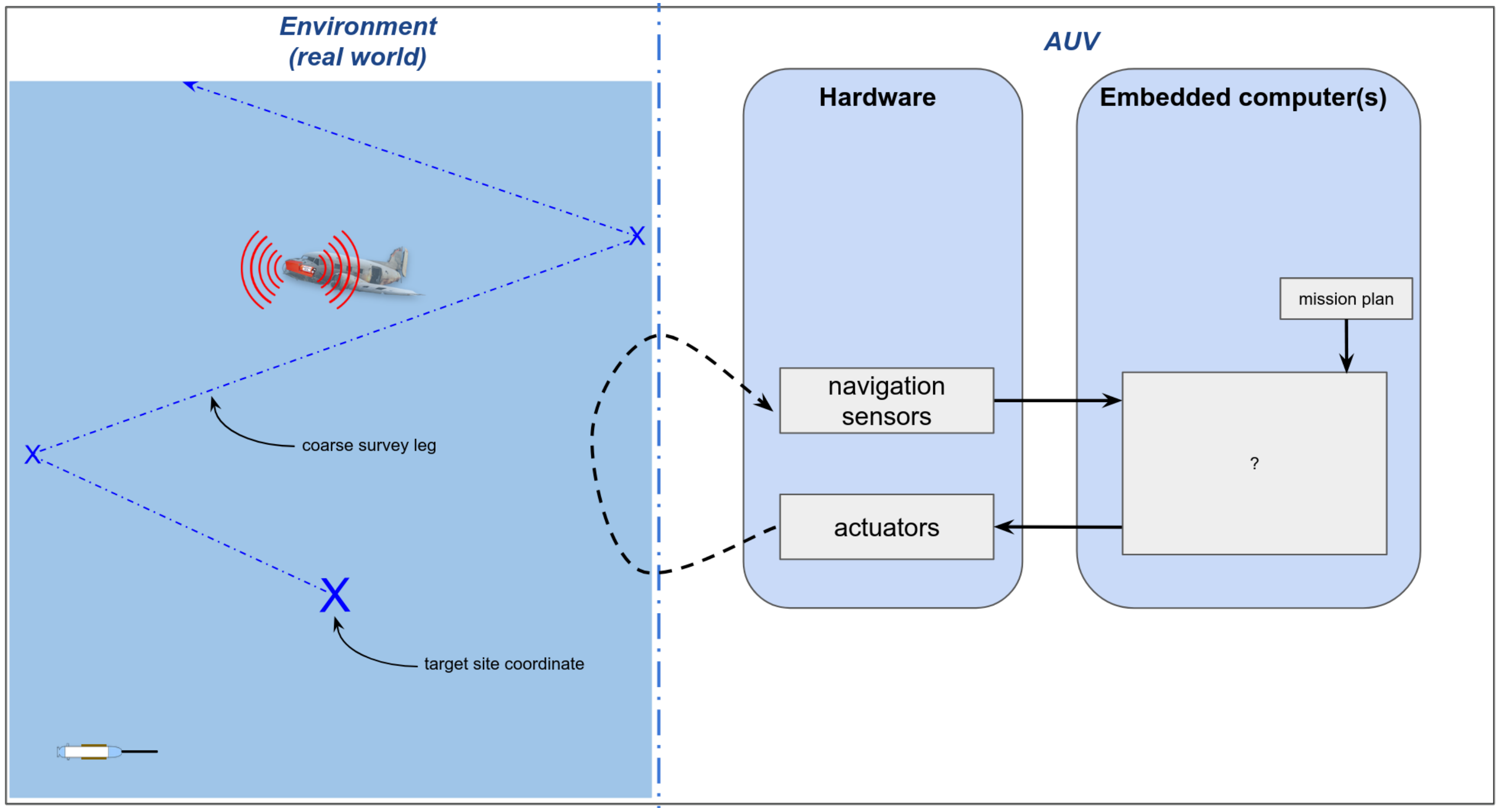




Higher-level Mission Plan

High-level mission parameters:

- The overall objective of the mission:
  1. Transit to the target site coordinates.
  2. Conduct a coarse survey until a pinger signal is detected.
  3. If detected, estimate the bearing to the pinger.
  4. Once the bearing is estimated with sufficient confidence, transit along that bearing while scanning the seabed.
  5. When/if the wreck is detected, conduct a fine lawn-mower pattern survey of the area.



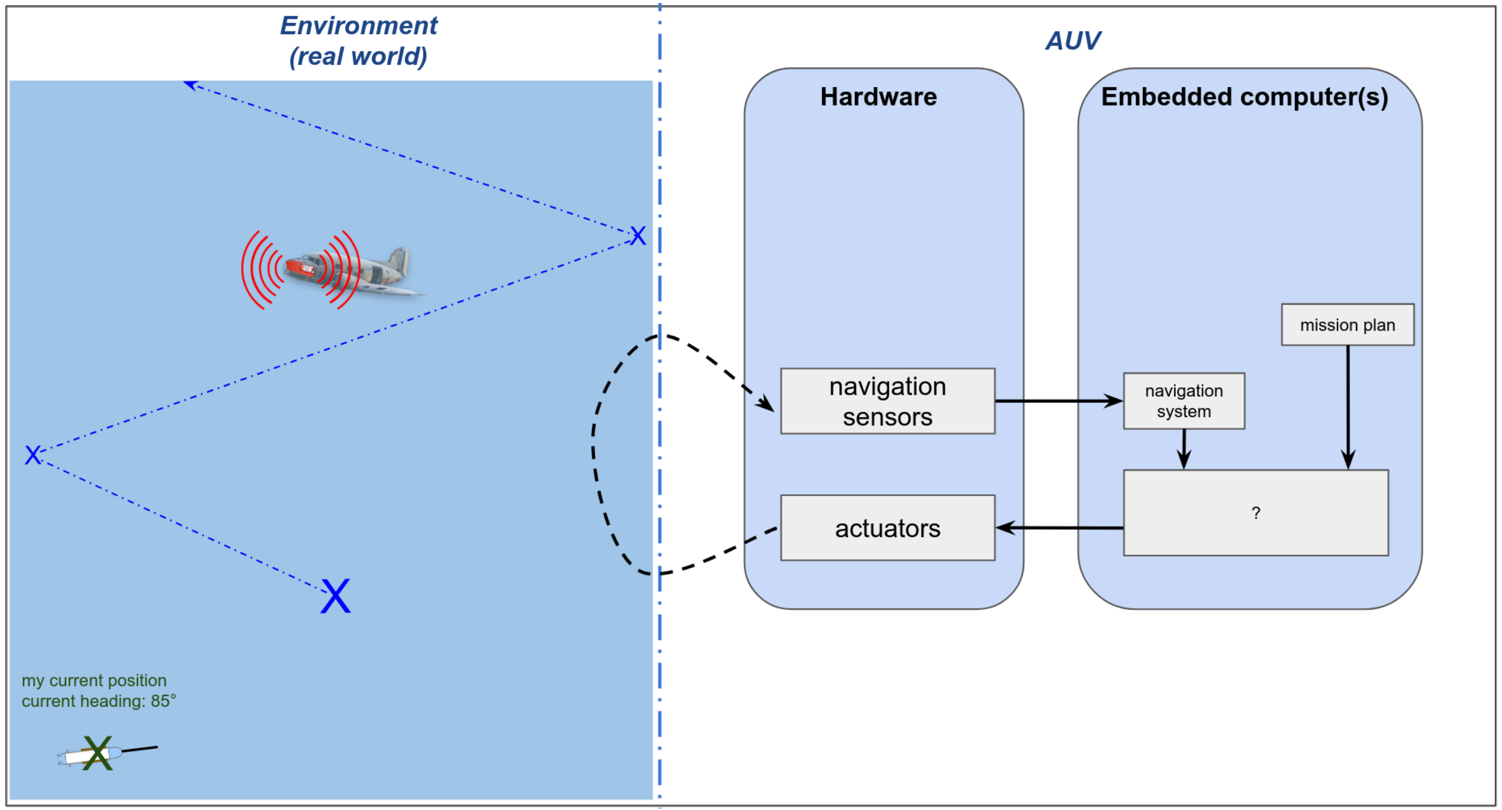
High-level safety parameters:

- Return to the recovery site by 18:00.
- Remain within a 10 km radius of the support vessel.
- Return to the recovery site if battery falls below 20%.
- Abort the mission and surface if a mechanical failure is detected.

Navigation System

The navigation system of the vehicle continuously computes:

- Position:
    - current latitude
    - current longitude
    - current depth
    - current altitude
    - position uncertainty
- Attitude:
    - current roll angle
    - current pitch angle
    - current heading angle
    - attitude uncertainty
- Velocity:
    - current surge speed
    - current sway speed
    - current heave speed

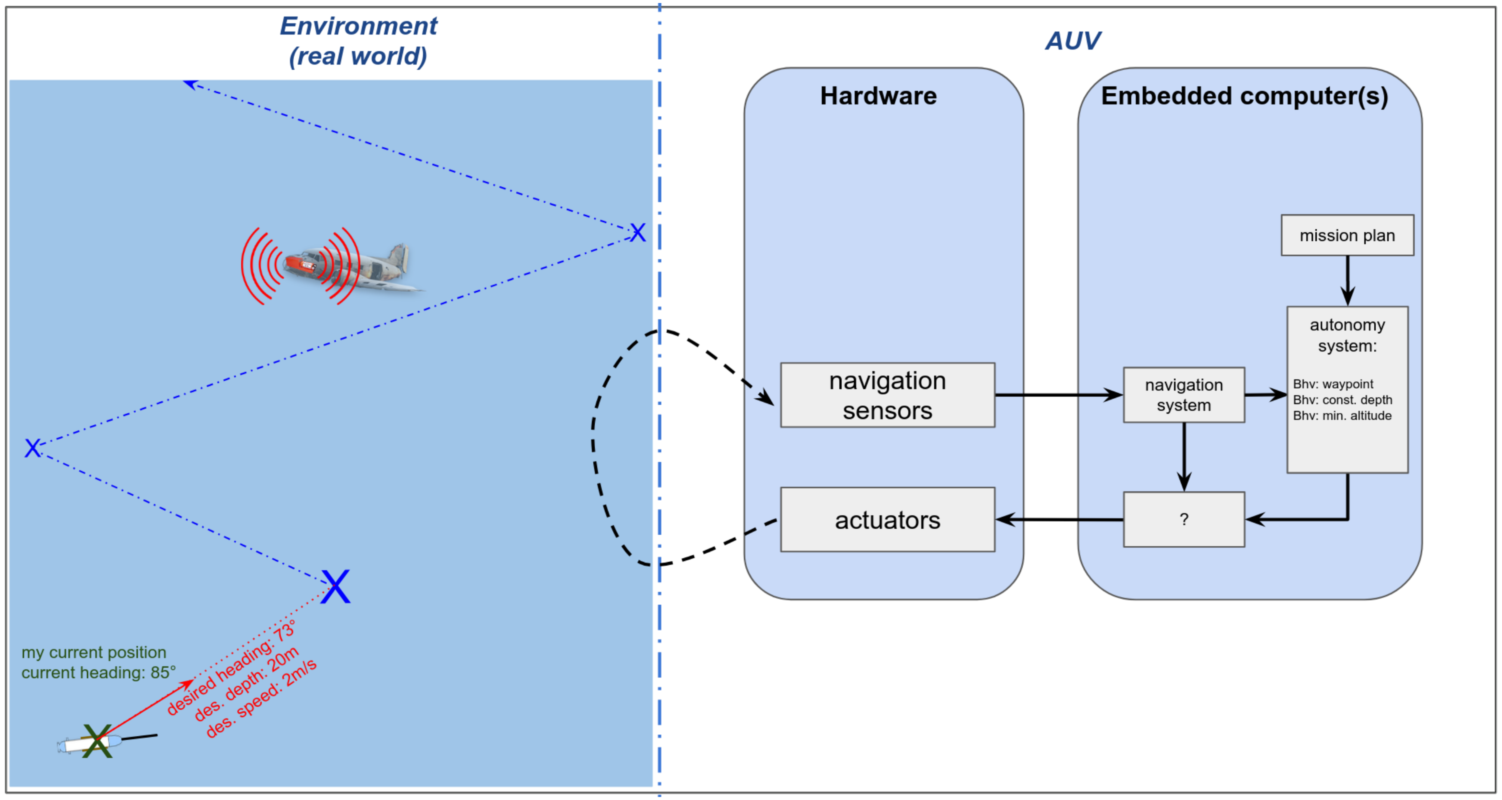


The autonomy system considers multiple objectives; for example:

- Current primary mission task (i.e., go to target waypoint)
- Mission timeout
- Safety behavior 1: Minimum altitude
- Safety behavior 2: Operational region

Considering all active objectives, the optimal course decisions are computed:

- desired heading
- desired depth
- desired speed



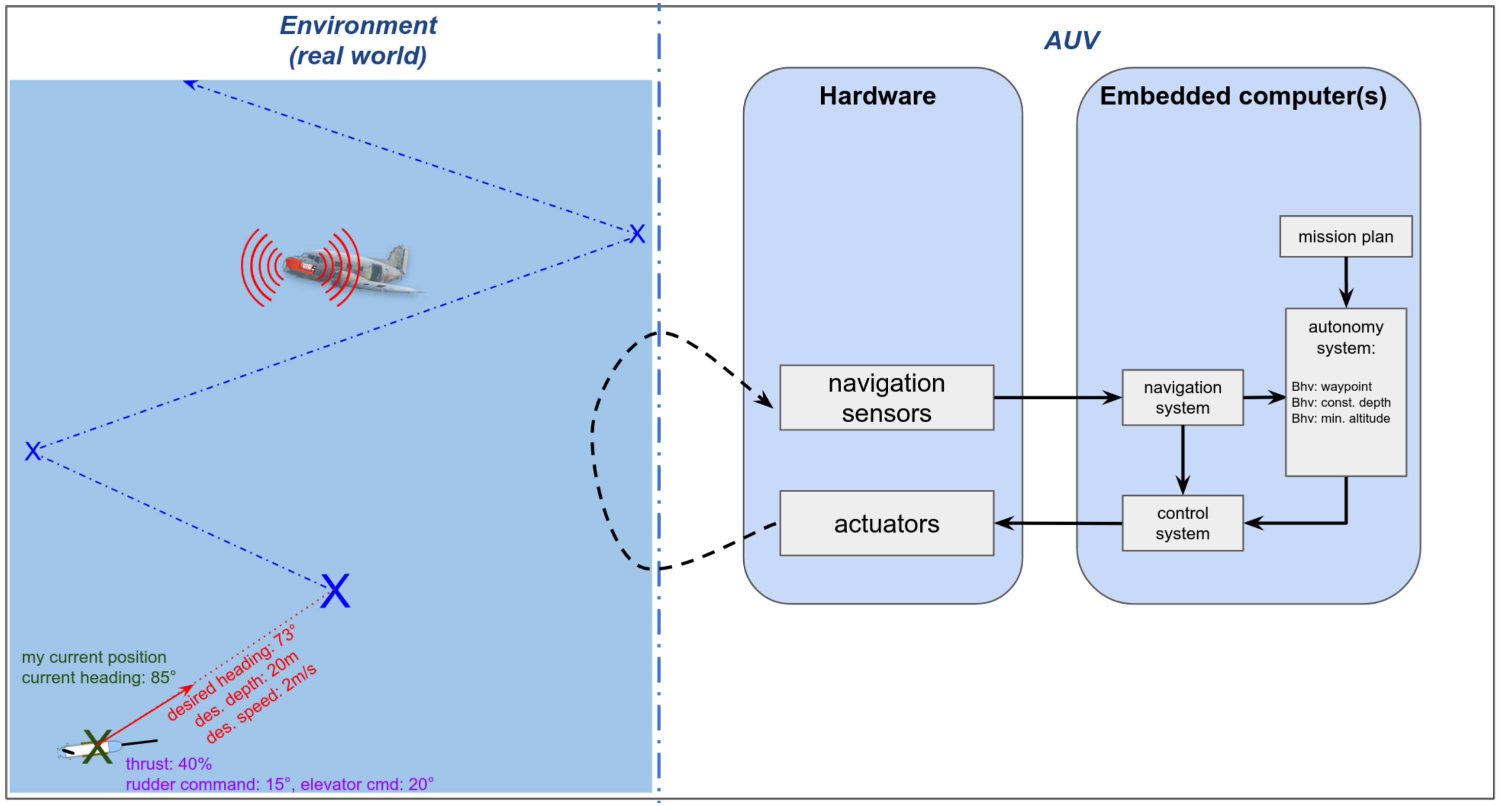
Control System

Purpose of the control system:

- Controls the actuators (i.e., control surface angles and thruster speed) to maintain desired heading, depth, and speed as commanded by the helm

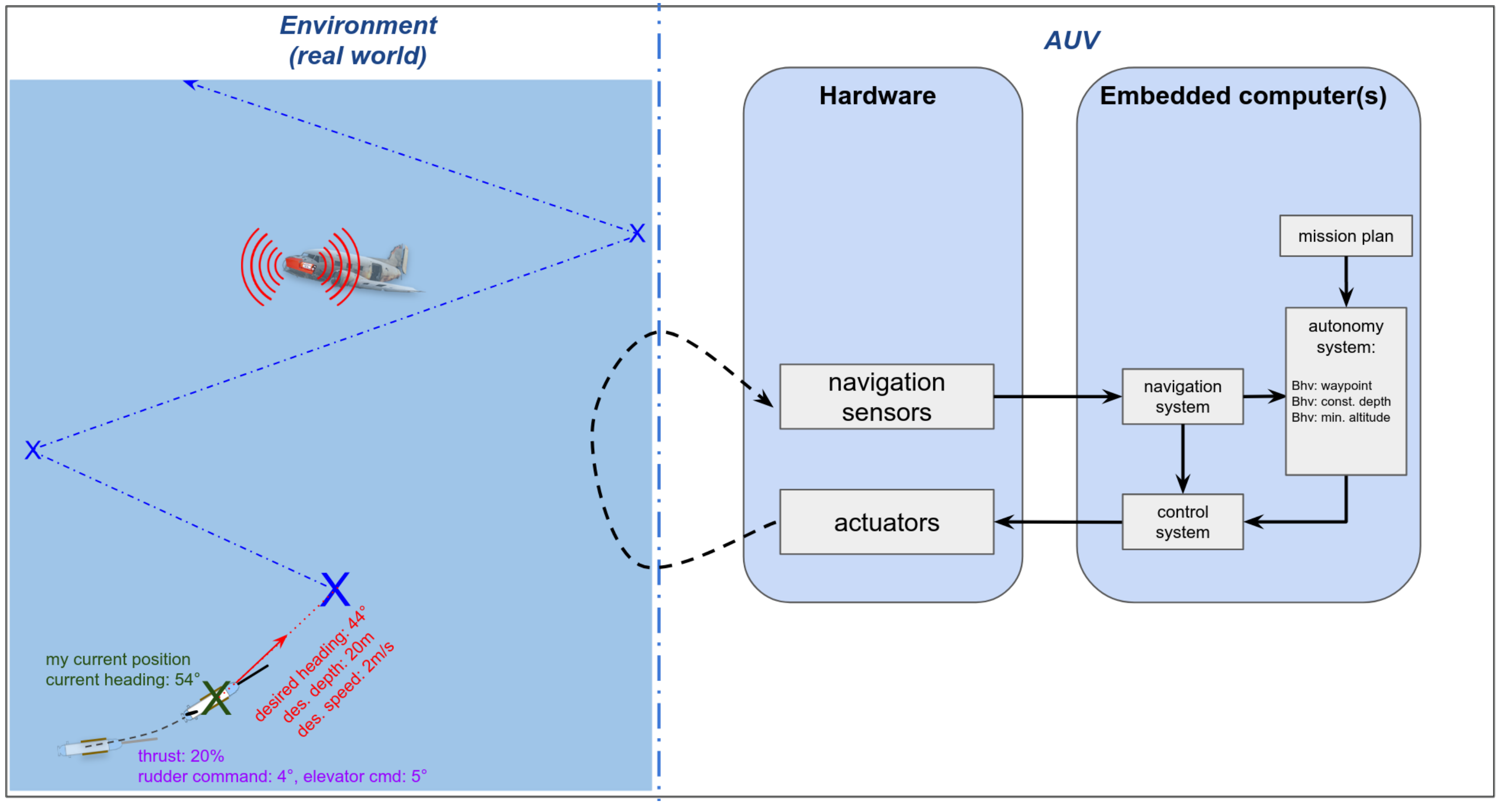
Common control algorithms:

- Proportional-integral-derivative (PID) control algorithm
- Model-based control
- Adaptive control



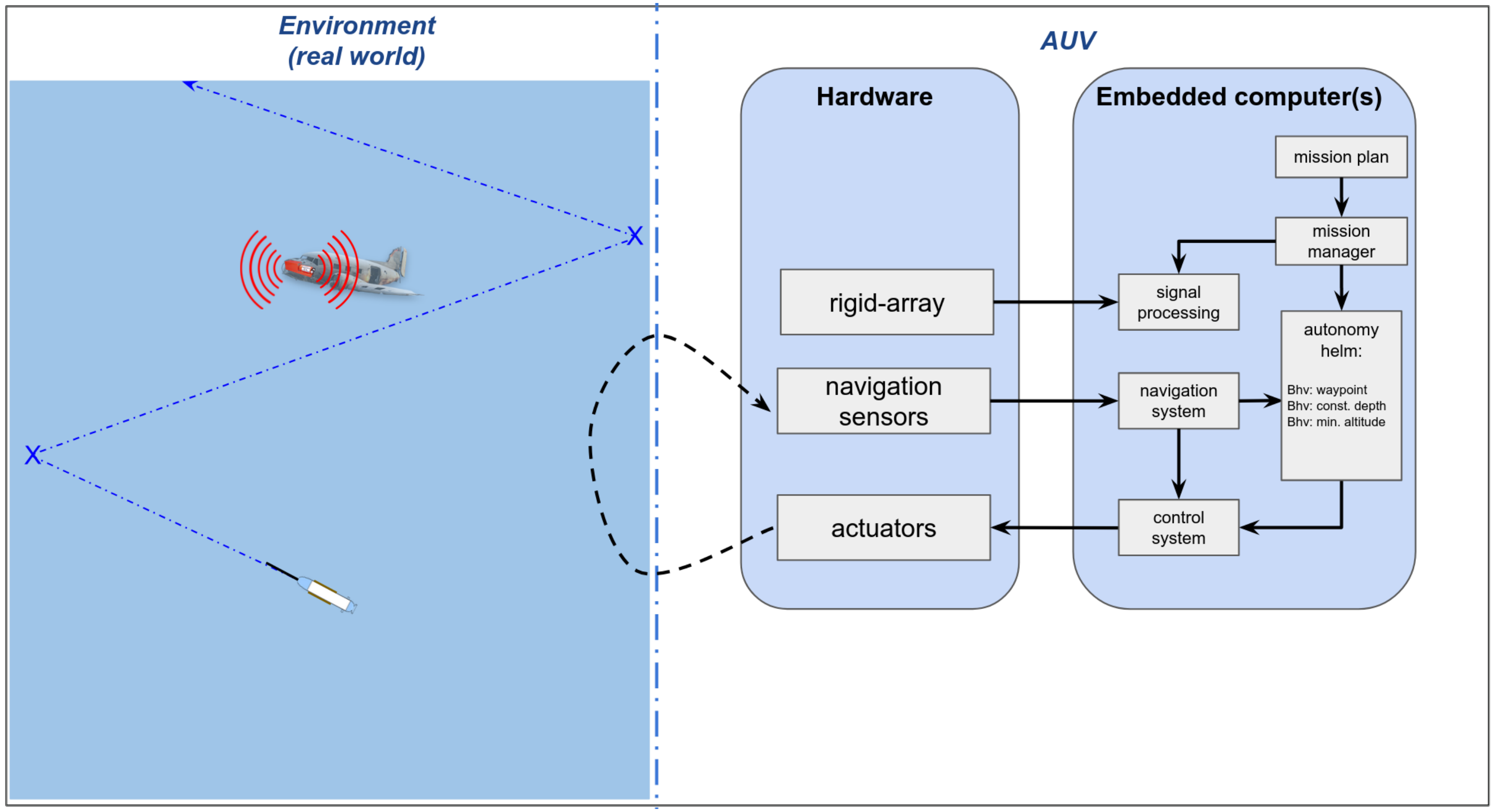
Sensing, navigation, autonomy, control and actuation. Repeat.

- Previous actuation will move the vehicle to a new position.
- Navigation system will use sensor data to compute the updated position.
- Based on the updated navigation solution and current objectives, autonomy system will update the desired course.
- Control system will compute the actuator commands to maintain the AUV in the updated desired course.
- This loop will iterate until the end of the mission...



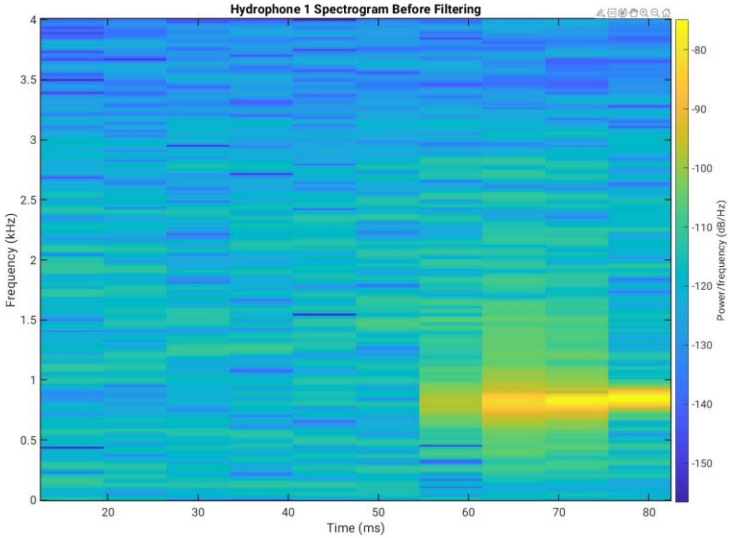
Mission Manager & Modes

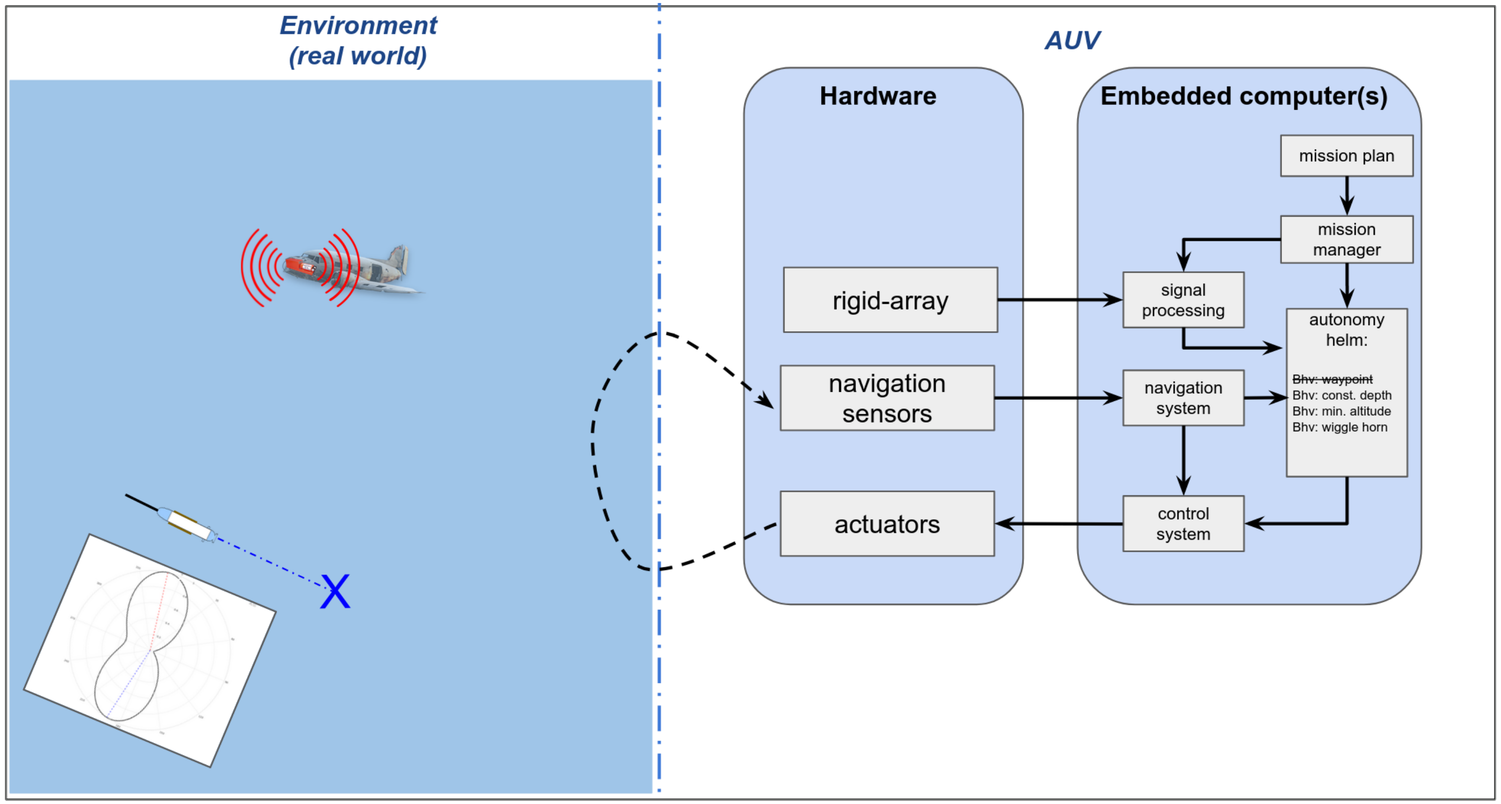
- A vehicle's system architecture and a mission may each contain multiple modes.
- The modes are managed by the "*Mission Manager*"
- The Mission Manager oversees the overall autonomy of the vehicle and coordinates many subsystems, including the helm, sensing modules, and navigation systems.
- In this example, once the AUV reaches the target site coordinate, the Mission Manager switches the vehicle to a new mode:
  - helm starts the coarse survey leg
  - data acquisition and signal processing subsystems are initiated



Adaptive autonomy behaviors using real-time payload sensor data

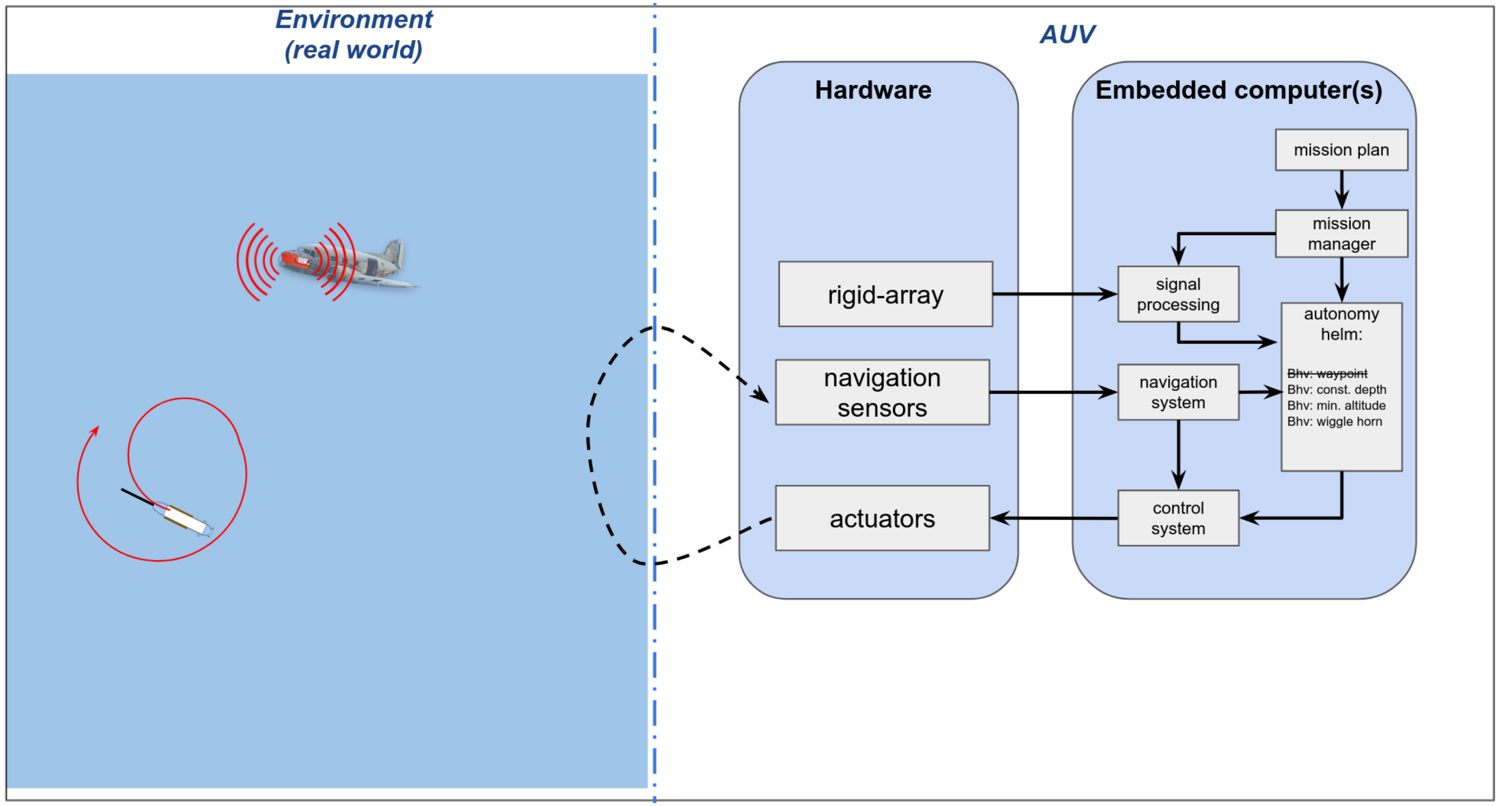
- The pinger signal is detected for the first time.
- The beamforming result is ambiguous.
- The estimated bearing could correspond to either the port or starboard side of the AUV.





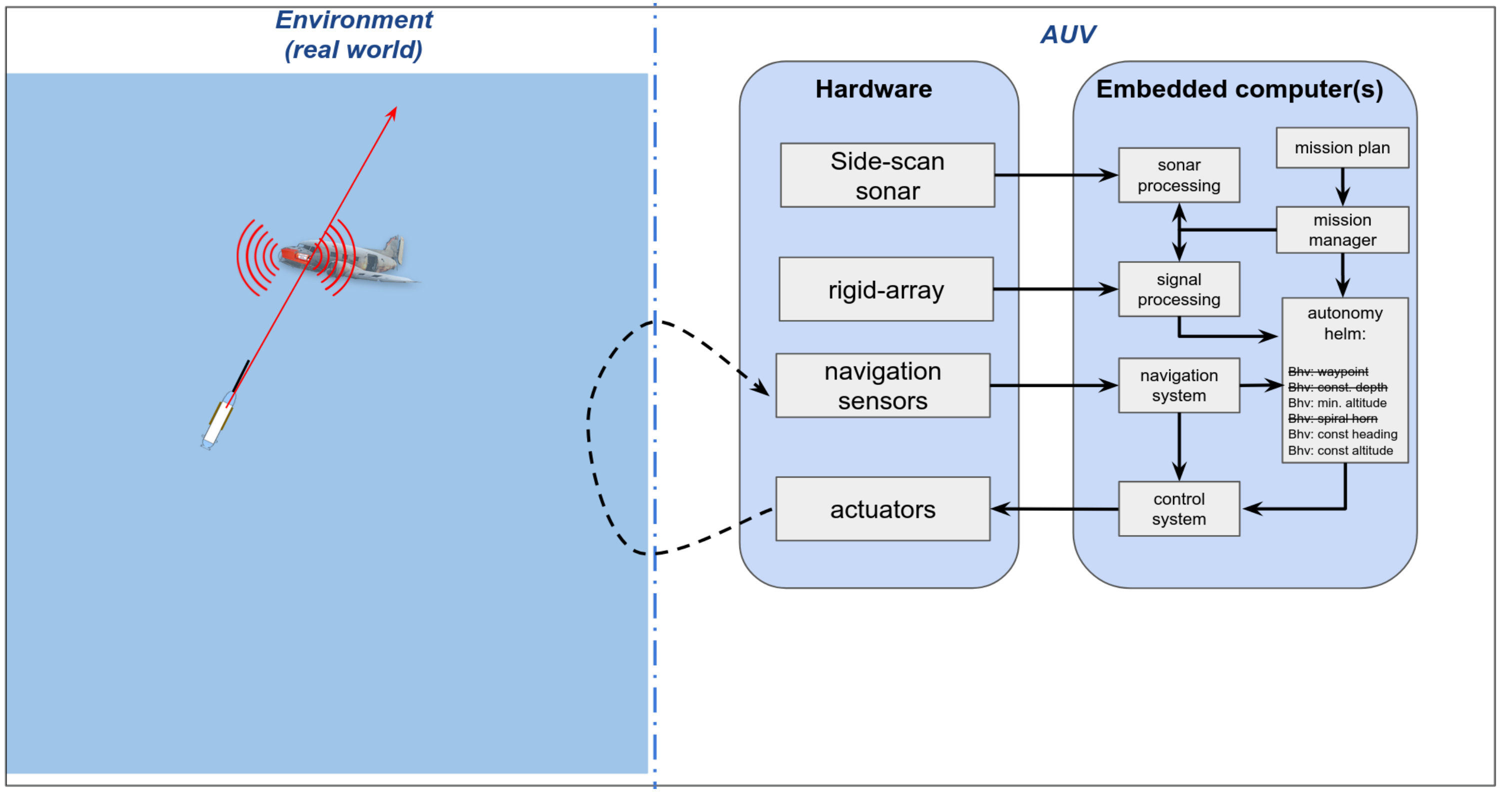
Adaptive autonomy behaviors using real-time payload sensor data

- The pinger signal is detected for the first time.
- The beamforming result is ambiguous.
- The estimated bearing could correspond to either the port or starboard side of the AUV.
- The Mission Manager switches the vehicle to an adaptive search mode.
- The autonomy helm triggers an adaptive behavior. Helm guides the AUV using real-time data from the rigid array to resolve the ambiguity.
- Once the ambiguity is resolved, the AUV obtains an estimate of the signal's direction of arrival.



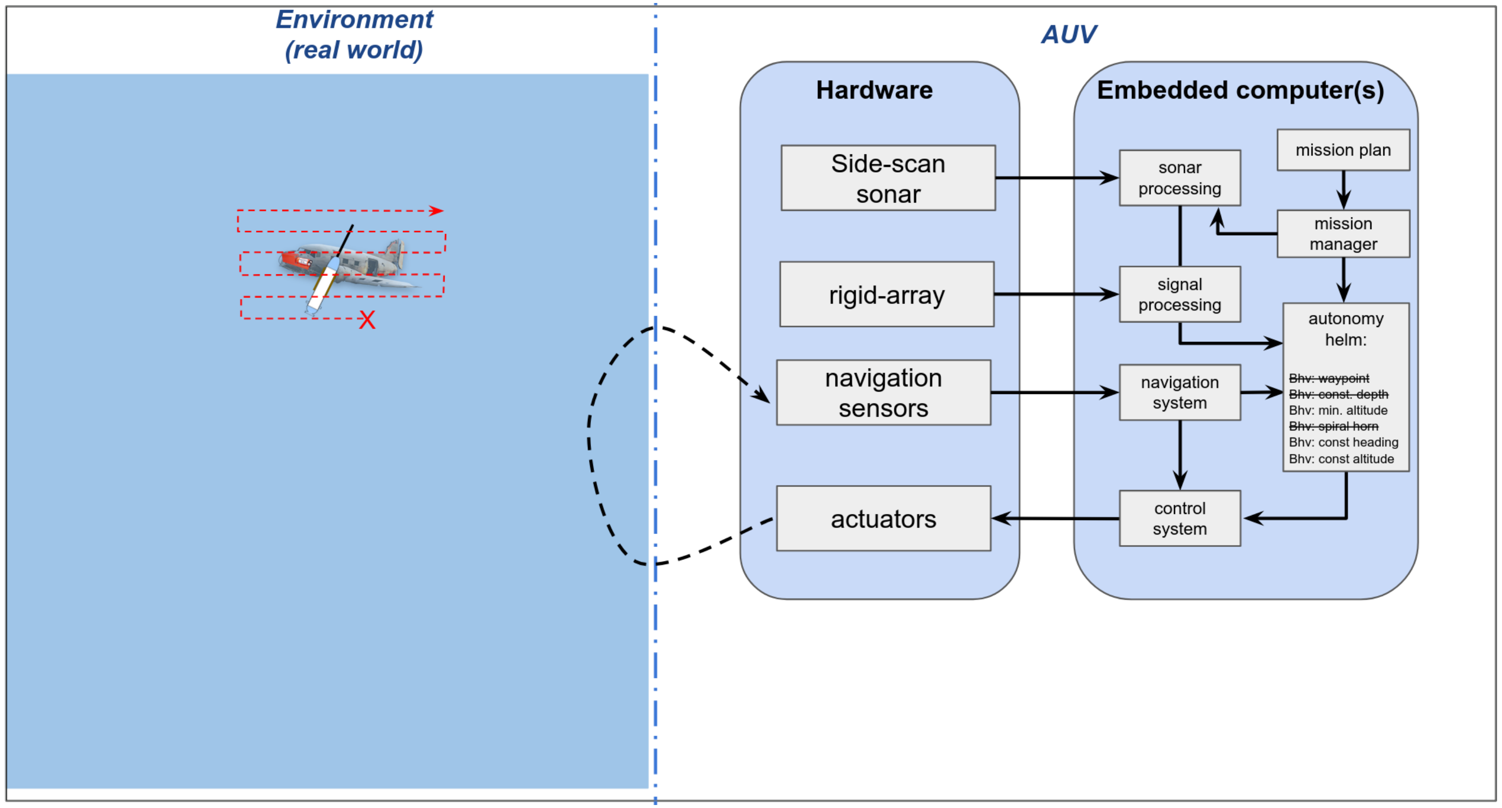
Adaptive autonomy behaviors using real-time payload sensor data

- Mission manager switches the vehicle to a bottom-surveying mode along the direction of arrival:
  - The side-scan sonar and associated processing chain are activated.
  - The helm initiates a bottom tracking behavior to maintain a constant altitude above the seabed.
  - Helm follows a constant course towards the signal's direction of arrival



Adaptive autonomy behaviors using real-time payload sensor data

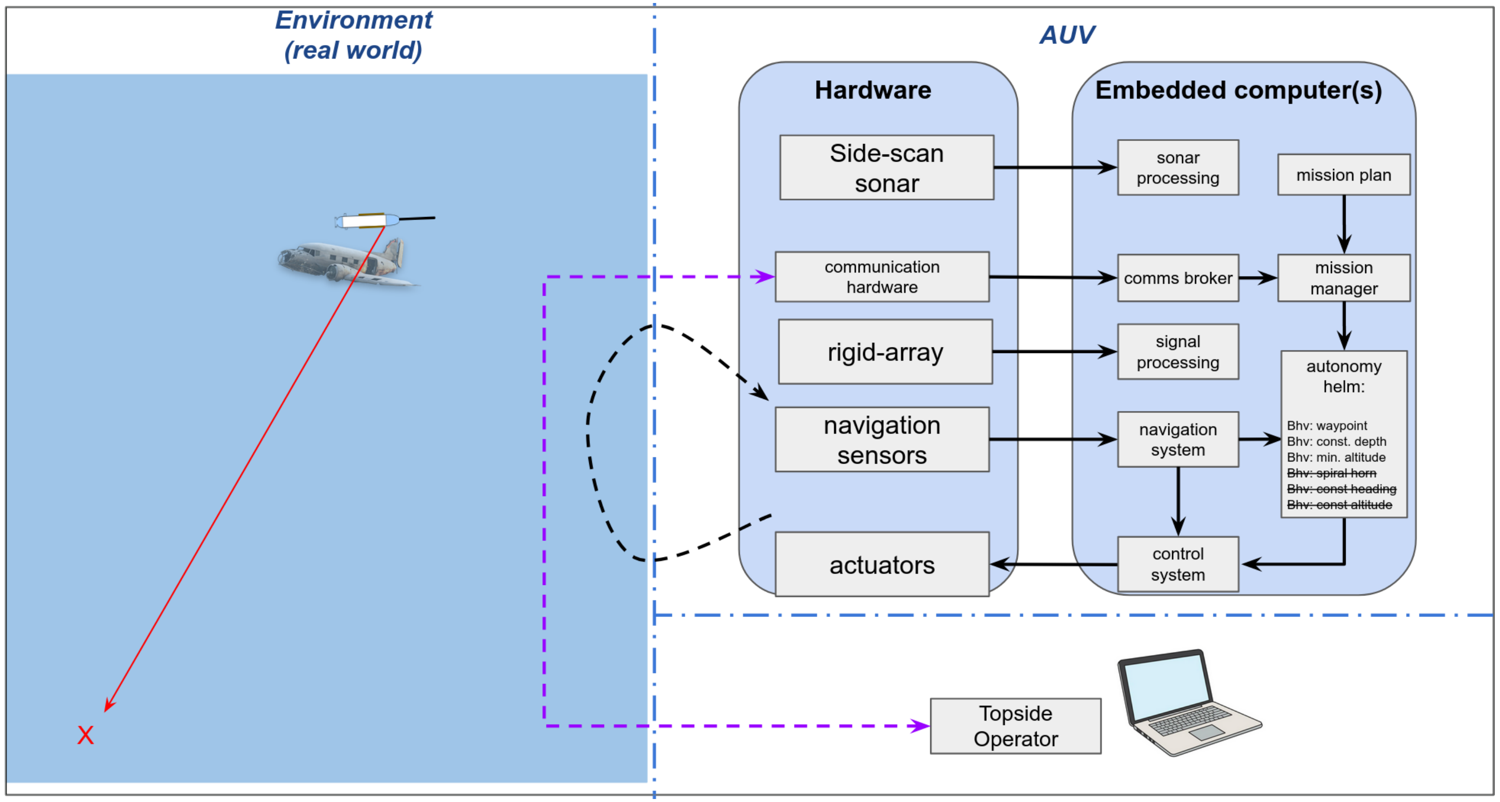
- Mission manager switches the vehicle to a bottom-surveying mode along the direction of arrival:
    - The side-scan sonar and associated processing chain are activated.
    - The helm initiates a bottom tracking behavior to maintain a constant altitude above the seabed.
    - Helm follows a constant course towards the signal's direction of arrival
- When the sonar processing chain detects the debris, the Mission Manager is informed.
- The Mission Manager then initiates a lawn-mower survey pattern to image the wreck.



Using operator inputs for autonomy

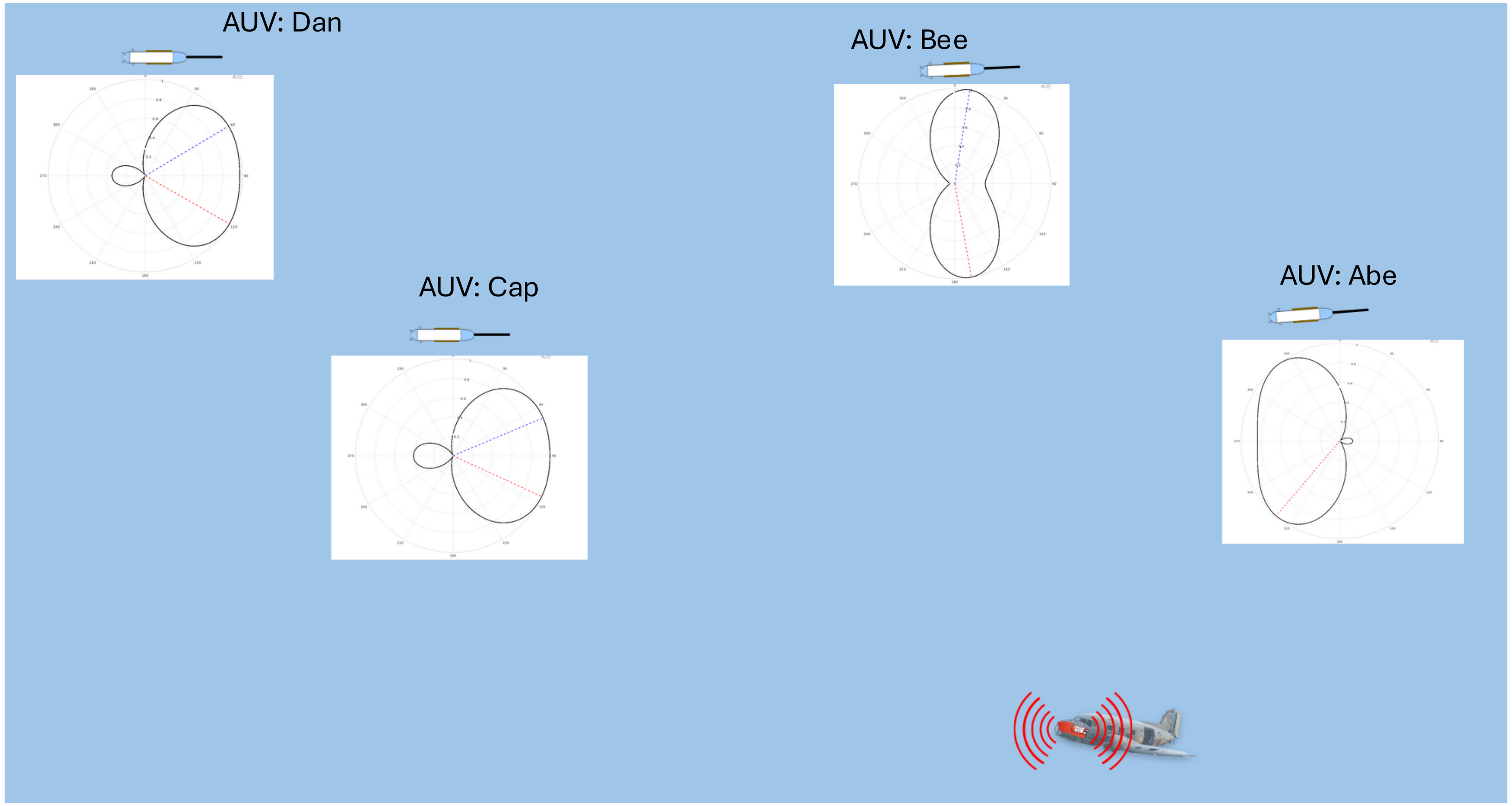
If equipped with communication hardware; such as an acoustic modem, satellite or cellular (surface only); the operator can update the AUV's mission plan in real time. For example:

- Abort the mission.
- Change mission parameters; such as:
  - Search location
  - Search pattern
  - Sensor parameters



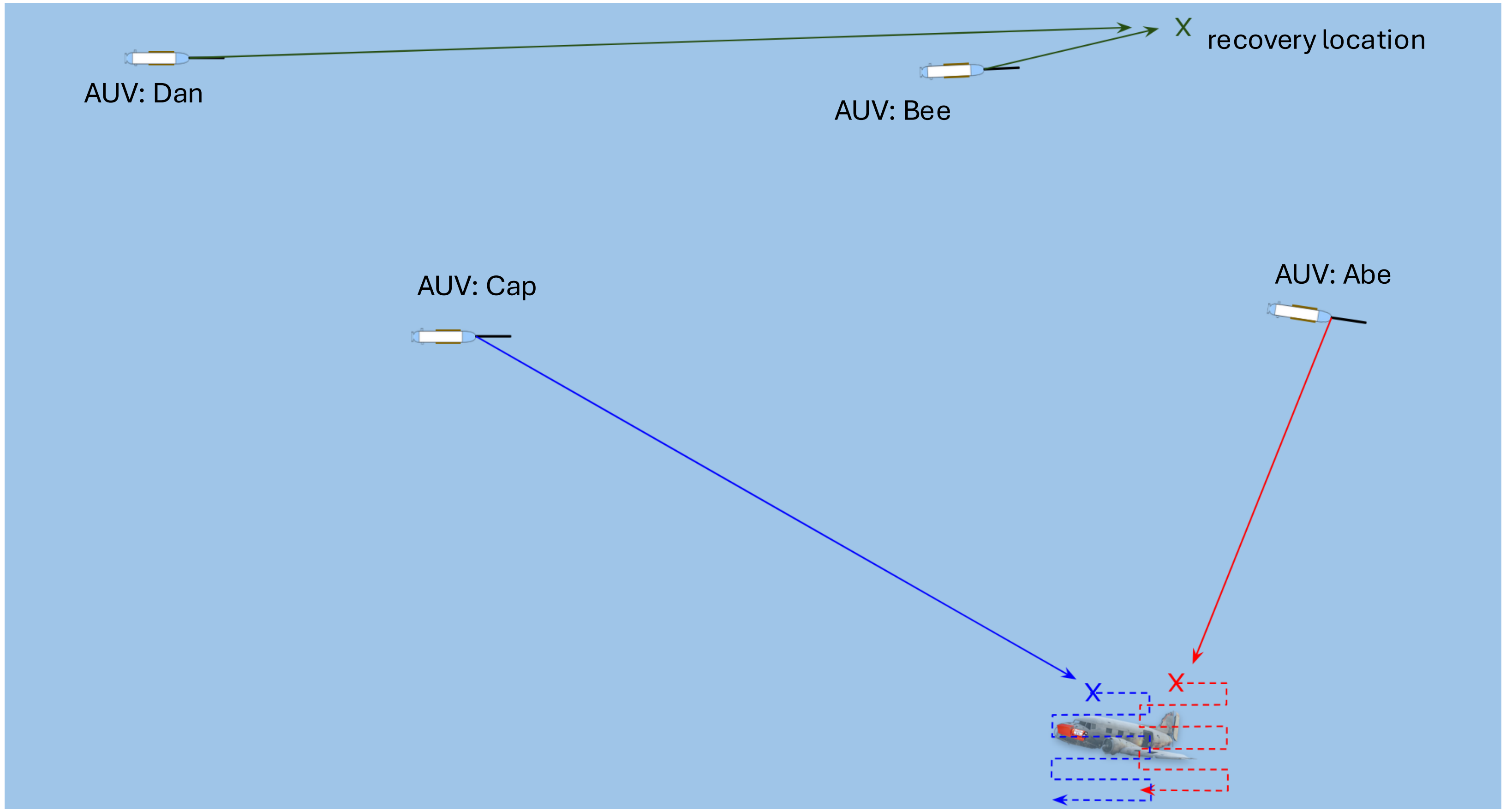
The Future: A fleet of collaborating AUVs

- If all AUVs are able to share their own knowledge, such as their individual beam-power measurements, the location of the pinger could be estimated almost instantaneously.
- The requirements for this to happen:
  - Each vehicle must know the relative or absolute positions of the other vehicles accurately.
  - The vehicle network must be able to communicate this information among the AUVs.
  - The AUVs must be sufficiently low cost.
  - The AUVs must be reliable enough to operate with minimal operator support; for example, it should not be necessary to assign a chase boat to every AUV.



The Future: Distributed Decision Making

- Once the pinger position is tracked, the AUVs may themselves decide which vehicles should continue surveying and which should return to the recovery site.
- This decision may be based on remaining battery, vehicle health, and distance to the target.
- For decentralized decision-making, each AUV should communicate with other vehicles, requiring multiple acoustic comms cycles.
- Current research focuses on reducing the number of required cycles.



End