Unmanned Marine Vehicles

Classes of UMVs:

1) U/W Remotely Operated Vehicles (ROVs) – continuously teleoperated

2) Autonomous/Unmanned Underwater Vehicles (AUVs/UUVs), preprogrammed to perform without human intervention, and

3) Unmanned Surface Vehicles (USVs) – robotic boats that can be teleoperated or operated autonomously without human input.
Remotely Operated Vehicles (ROVs)

Applications:
- subsea inspection
- pipeline installation
- trench digging
- maintenance
- construction

Control: remote teleoperation (may be semi-autonomous)

Sensors/Instrumentation: video cameras, lights.

Advantages: Data transfer/power use umbilical – virtually unlimited power for propulsion/tooling; Human operators can perform more complex tooling motions.

Disadvantages: Limited range; need constant human supervision; need complex mooring systems to decouple wave-induced motions and prevent entanglement.

Future: Hybrid AUV/ROV.
- Transit untethered (automatic control).
- Deployable from many platforms.
- Travel ~8 hours at speeds of ~3-4 knots

Oceaneering Nexxus ROV

Saab Double Eagle SAROV
Autonomous Underwater Vehicles (AUVs)

Applications:
- Ship hull inspection
- Underwater survey
- Oceanographic sensing
- Plume tracking
- Vehicle/Animal Detection or Tracking

Control: Preprogrammed automatic control
Sensors/Instrumentation: Sonar (mapping), USBL (localization), Water Column (CTD, CDOM, \( O_2 \), etc.).

Advantages: Deployable from many platforms; can travel ~8 hours at speeds of ~3-4 knots; can perform many missions without human intervention.

Disadvantages: Onboard power restricts range – glider technologies can circumvent; limited tooling capabilities.
Autonomous Underwater Vehicles (AUVs)

E-Field Sensor Development
Autonomous Underwater Vehicles (AUVs)

E-Field Sensor Development
Unmanned Surface Vehicles (USVs)

Applications:
• Ocean sampling
• Maritime search and rescue
• Hydrologic surveys
• Harbor surveillance
• Underwater Inspection
• Defense

Control: Automatic control or teleoperated

Sensors/Instrumentation: Stereo cameras, LiDAR, Radar, GPS.

Advantages: Deployable from many platforms; can perform many missions without human intervention.

Disadvantages: Onboard power restricts range; can be susceptible to wave, current & wind; interaction with civilian vessels.
USV Challenges: Disturbance Rejection

USV Design: Hullform

Do not need to accommodate human operators – design more optimized for sensing, maneuvering or deployment requirements.

Expected operating conditions suggest semi-displacement vessels:

1. SWATH (e.g. Marquardt et al. 2014; Kitts et al. 2012)
2. Catamarans (e.g. Sarda et al. 2015)
USV Design: Autonomy (Station Keeping)

1. Inspections may require object localization, feature imaging and the launch and recovery of smaller subsystems – stationkeeping essential.
2. Winds, tides and waves – can vary substantially, in time and space, as a USV maneuvers around a bridge structure → robust stationkeeping.
3. Typical low weight and high windage of USVs can make this challenging.
4. Nonlinear MIMO and Backstepping stationkeeping controllers (Sarda et al. 2015)
5. Wind Feedforward Control – wind models, sensor number and placement (Qu & von Ellenrieder 2015).
USV Challenges: Disturbance Rejection

WAM-V USV16 during on-water station-keeping tests in the Intracoastal Waterway
USV Challenges: Disturbance Rejection

Position and heading errors for sliding mode station-keeping controller with/without wind feedforward control at Location 1.
USV Challenges: Positioning

1. Operating near a large structures can affect precise positioning:
   a) GPS line of sight to overhead satellites blocked
      i. Kalman-filter sensor fusion combining dead-reckoning and GPS
      ii. Real Time Kinematic (RTK) GPS positioning technology
   b) System Localization and Mapping (SLAM)
2. Large bridge structures can affect compasses (flux-gate)
3. Cooperative sensing/Multi-session Mapping
   a) Use of SLAM to capture changes in bridge structures using maps obtained over repeated bridge inspections.
   b) Can increase efficiency and quality of maps using informative path planning for active mapping in SLAM (Kim & Eustice 2015)
UxV Multi-domain Systems

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USV Challenges: ALR
USV Challenges: ALR

Variable mass and drag during ALR
USV Challenges: Multiple Vehicle Interaction

Field Testing of Dynamics-Aware COLREGs-Compliant Behaviors for USVs

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**Motivation:** Non-trivial trajectory planning and tracking challenges

Congested harbor scenario
(Source: Map data ©2013 Google)

USV encountering COLREGS “crossing from right” situation

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USV Challenges: Multiple Vehicle Interaction

Not possible to anticipate the infinite number of possible situations a USV might encounter – combination of advanced deliberative/reactive task and trajectory planning is needed.

- “Automatically-generated” behaviors that allow planner to consider classes of situations in pre-programmed ways, while accounting for limitations of the vehicle’s dynamic response (Bertaska et al. 2015).
- Model-predictive trajectory planning for operations in civilian traffic (Shah et al. 2014) – contingency maneuvers; COLREGs
USV Challenges: Multiple Vehicle Interaction

- WAM-V USV14 simulation model
  - Lattice-based global trajectory planner
    - USV control action space discretized into a set of dynamically feasible motion commands
    - Planner utilizes A* search to find a collision-free, dynamically-feasible trajectory $\tau = \{w_i \mid w_i = [x, y, \theta, t]^T\}$ between the current USV’s state and motion goal

- Meta-model of WAM-V USV14’s dynamics and control
  - COLREGs-compliant local trajectory planner
    - Adaptively samples space of reachable motion goals based on temporal-spatial distribution of obstacle vessels and history of detected collisions during the search:
      a) prioritized sampling of entire set of state space trajectories in each sampling cycle
      b) sampling of individual state space trajectories for collision detection

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USV Challenges

Calculation of Closest Point of Approach (CPA) distance and time for initiation of COLREGs-Compliant Maneuvers (Bertaska et al. 2015).

COLREGs rule for each OMT vessel is determined by its current position with respect to USV (Bertaska et al. 2015).
USV Challenges: Multiple Vehicle Interaction

EXPERIMENTAL SETUP

USV12
- Automatic Control Box
- Motor Pods
- Inflatable Pontoons

DUKW-Ling
- Automatic Control Box
- Model ISO Container
- SWATH Hullforms

USV14
- Automatic Control Box
- Guidance Computer
- Inflatable Pontoons
- Motor Pods

Jonboat

Experimental platforms
USV Challenges: Multiple Vehicle Interaction

EXPERIMENTAL RESULTS

Follow-behavior

Head-on and crossing-from-right COLREGs situations

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USV Challenges: Multiple Vehicle Interaction

EXPERIMENTAL SETUP
USV Challenges: Autonomy

a) Small teams, 3-5 people, maybe with ALR

b) Some locations difficult to access – system small/light for small truck transport and tended by small boat.

c) Autonomy:
   i. Does not need continuous monitoring by human team.
   ii. Should permit teleoperation or redirection to areas of interest (RSC).
   iii. Capable of autonomously resuming normal operation after interruption (sliding autonomy).

d) Constant communications with auto reconnect.

e) GUI: near real time; bright sunlight; outdoor working conditions; balanced operator workload.

f) Other boat traffic: COLREGs; dynamic obstacle avoidance.
USV Challenges: Autonomy

Multilayered Software Architecture.
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Disclaimer:
The opinions, findings and conclusions expressed in this presentation are those of the author and not necessarily those of the Florida Dept. of Transportation or the U. S. Dept. of Transportation.