AIS-Based Collision Avoidance in MOOS-IvP using a Geodetic Unscented Kalman Filter

Blake Cole

Laboratory for Autonomous Marine Sensing Systems
Massachusetts Institute of Technology
Woods Hole Oceanographic Institution

MOTIVATION

- Collision avoidance is a vital capability for autonomous surface vessels (ASVs) operating in public waterways

CHALLENGES

- Line-of-sight sensors are expensive, difficult to interpret, and subject to occlusion and environmental degradation
- AIS is relatively robust due to the characteristics of VHF radio propagation, but updates are sparse; previous approaches attempt to "fill in the gaps" using an Extended Kalman Filter (EKF) [1]
- The EKF requires definition of a local planar coordinate system, in order to describe vessel kinematics in an easily differentiable form; this is computationally inefficient

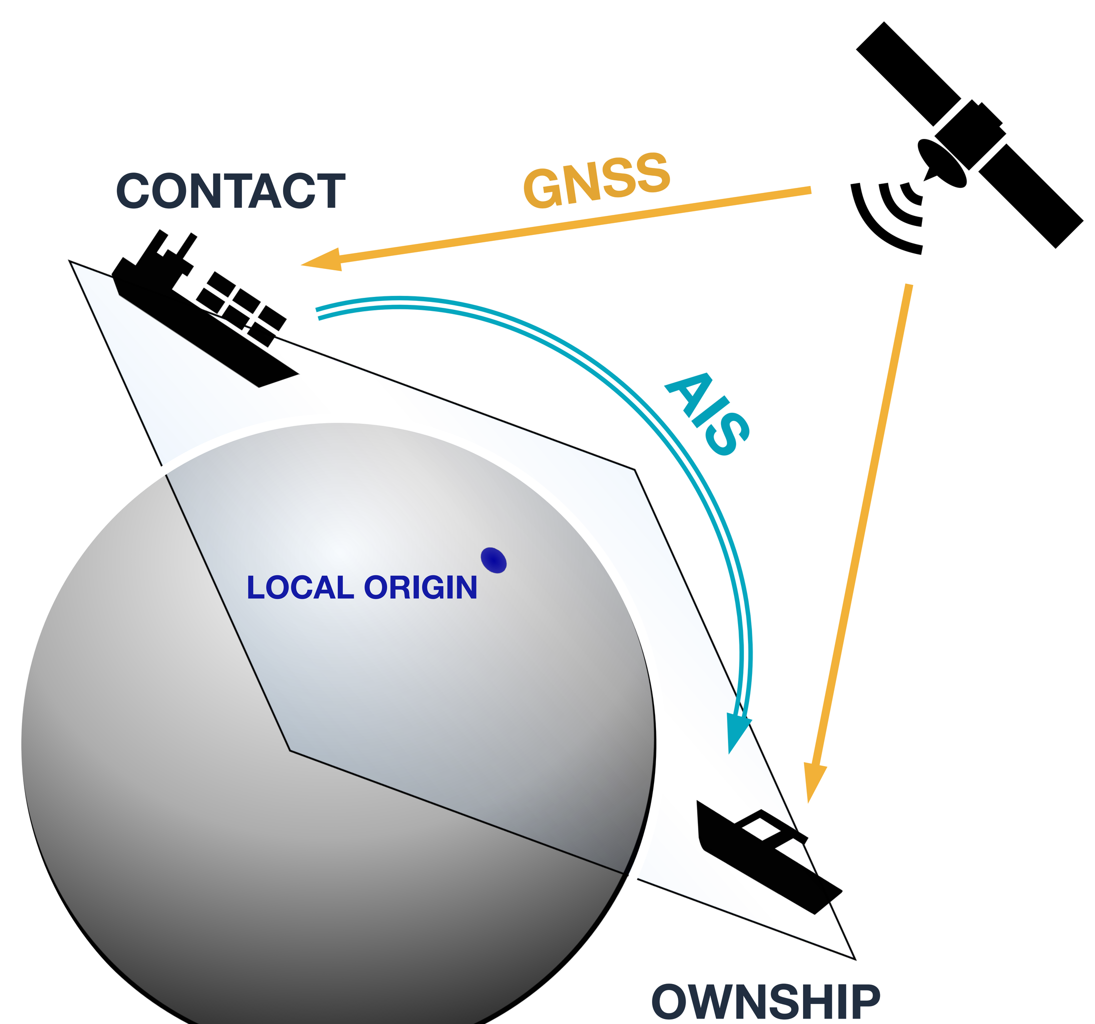
METHODOLOGY

1. AIS messages received asynchronously, decoded
2. Geodetic UKF [2] estimates contact position, speed, and heading in between AIS updates
3. MOOS-IvP [3] contact manager spawns new behavior whenever either of two values falls below threshold:
   - Vehicle separation
   - Closest point of approach (CPA)
4. COLREGS behavior alters objective function, penalizing combinations of heading and speed which are likely to result in a near-miss or collision

GOAL: Avoid Collision

SUBGOAL: Track Nearby Vessels

APPROACH: Geodetic UKF

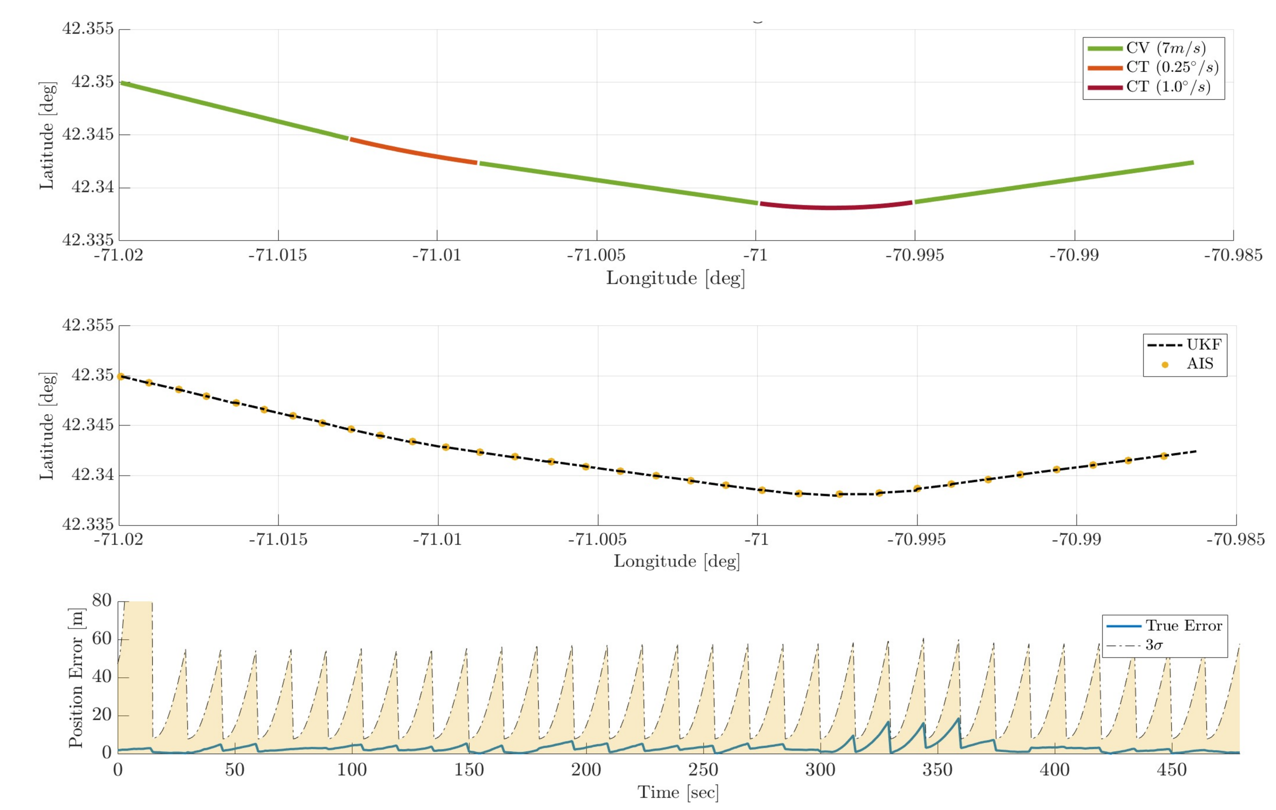


$$\begin{bmatrix} lon \\ lat \\ U \\ \alpha \end{bmatrix}_k = \begin{bmatrix} lon_{k-1} + atan2\left[\sin\left(\frac{U_{k-1}\Delta t_k}{R}\right)\sin(\alpha_{k-1}),\ \cos(lat_{k-1})\cos\left(\frac{U_{k-1}\Delta t_k}{R}\right) - \sin(lat_{k-1})\sin\left(\frac{U_{k-1}\Delta t_k}{R}\right)\cos(\alpha_{k-1})\right] \\ \arcsin\left[\sin(lat_{k-1})\cos\left(\frac{U_{k-1}\Delta t_k}{R}\right) + \cos(lat_{k-1})\sin\left(\frac{U_{k-1}\Delta t_k}{R}\right)\cos(\alpha_{k-1})\right] \\ U_{k-1} + a_{k-1}\Delta t_k \\ \alpha_{k-1} + r_{k-1}\Delta t_k \end{bmatrix}$$

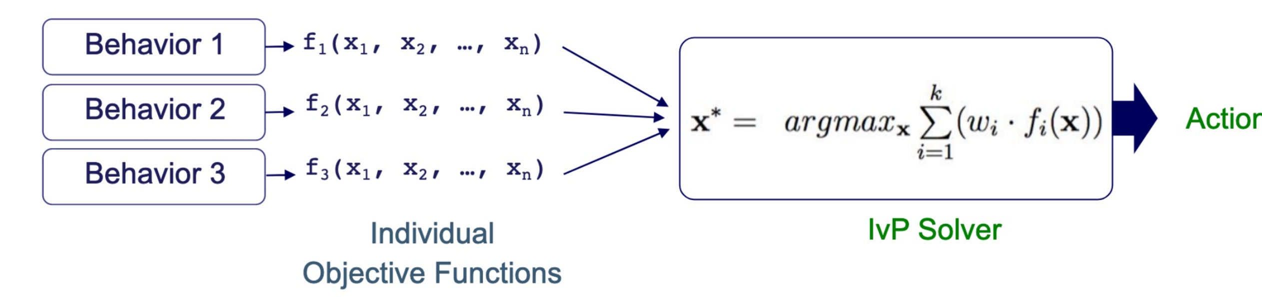
The Geodetic UKF eliminates the need to define an intermediate local coordinate frame.

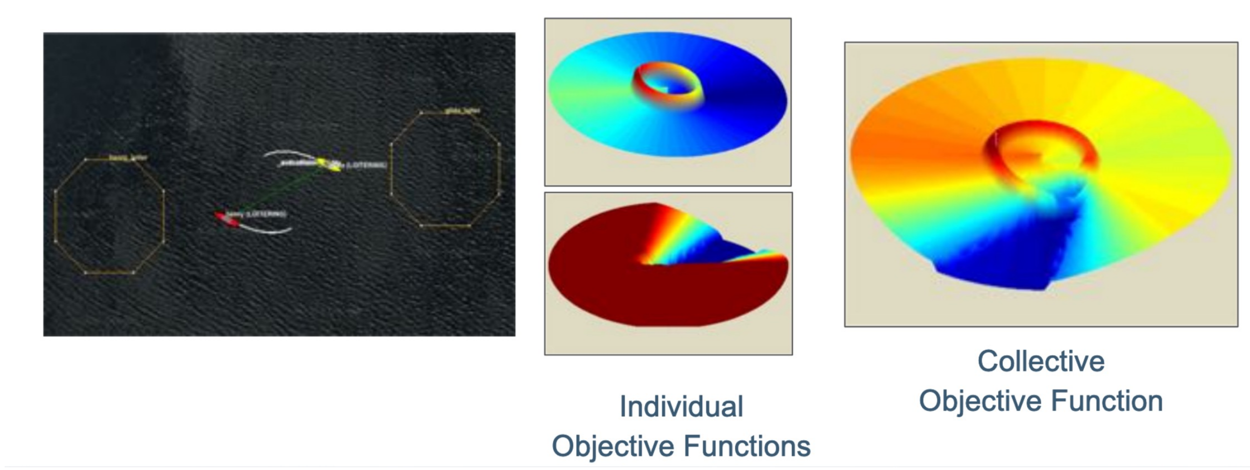
This improves computational efficiency, and makes the operating region more interpretable.

TRACKING SIMULATION

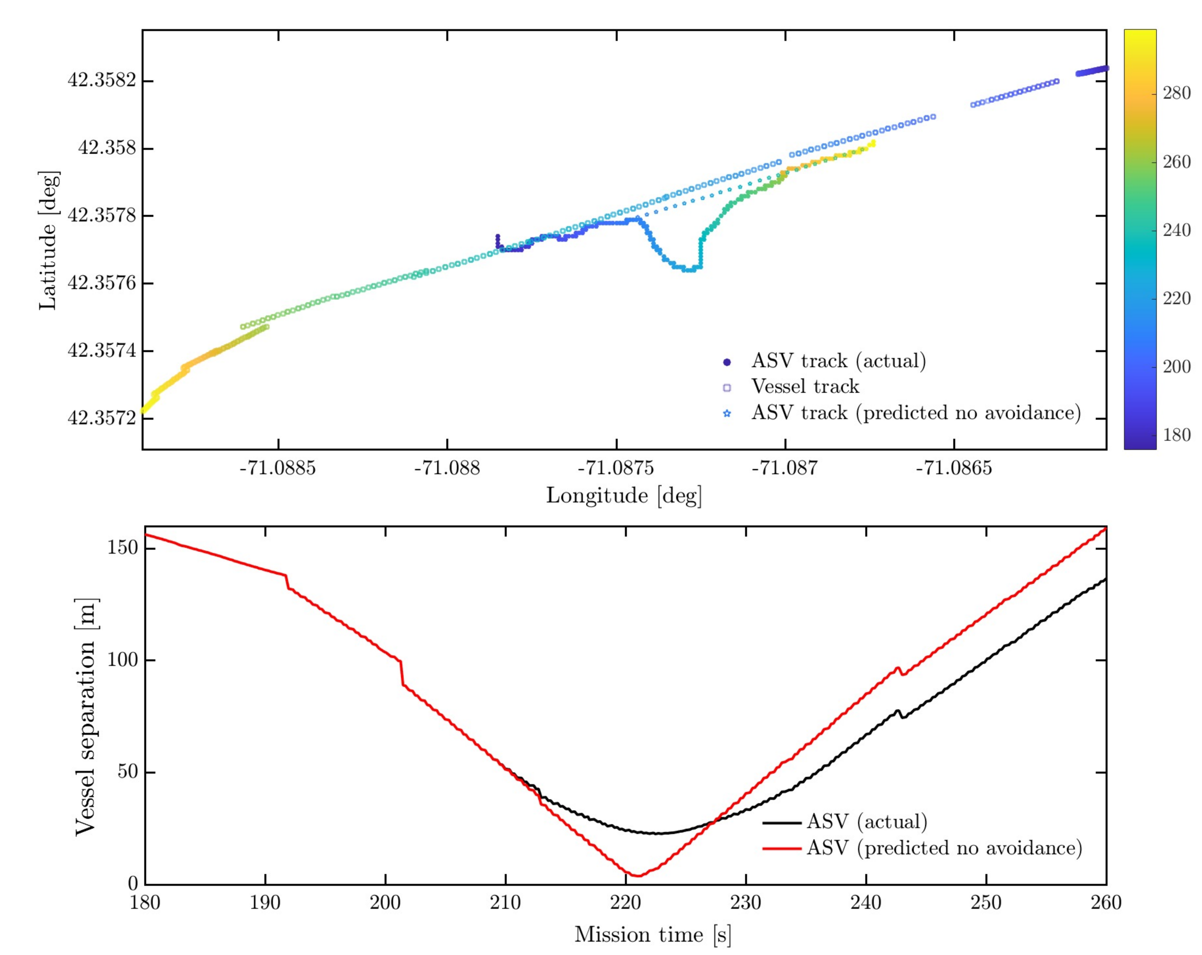


COLLISION AVOIDANCE IN MOOS-IVP





RESULTS



- The proposed AIS-based collision avoidance architecture performed admirably, keeping the ASV out of harm's way
- **Minimum separation increased from 3.8 m to 22.6 m**
- No human intervention required

REFERENCES

[1] Fossen and T. Fossen, "Extended Kalman filter design and motion prediction of ships using live automatic identification system (AIS) data," in *2nd European Conference on Electrical Engineering and Computer Science*, 2018

[2] B. Cole and G. Schamberg, "Unscented Kalman Filter for AIS-based vessel tracking in geodetic coordinates," *IEEE J. Oceanic Eng.*, 2021, Manuscript in review.

[3] M. R. Benjamin, H. Schmidt, P. M. Newman, and J. J. Leonard, "Nested autonomy for unmanned marine vehicles with MOOS-IvP," *Journal of Field Robotics*, vol. 27, no. 6, pp. 834–875, 2010

CO-AUTHORS

Michael R. Benjamin[1,2]
Supun Randeni[1]

[1] Computer Science & Artificial Intelligence Laboratory, Massachusetts Institute of Technology
[2] Department of Mechanical Engineering, Massachusetts Institute of Technology

ACKNOWLEDGEMENTS

The authors would like to thank the Office of Naval Research for their continued support of the oceanographic sciences, as well as the Schmidt Ocean Institute for sponsoring the IEEE OCEANS 2021 Student Poster Competition. This work was supported in part by the DOD-SMART Scholarship for Service Program.