Object Tracking for Uncrewed Surface Vehicles

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INSIDE OUT

Small uncrewed surface vehicles (USVs) are increasingly used for ocean environmental monitoring, seafloor mapping, and surveillance. Typically, USVs are equipped with cameras providing situational awareness, safe navigation, and capacity for solving a wide range of other tasks. However, having a human operator watch video streams continuously is expensive and inefficient, and only possible if the video can be transmitted ashore in real time – rarely an option on the ocean where data must be transmitted via satellites. Therefore, it is imperative for the USV to extract actionable insights from the video streams on its own through computer vision algorithms. At the most basic level, these algorithms must detect, locate, and classify objects appearing in the camera's field of view, track objects in time, and relay observations to shore in a condensed form. Moreover, since USVs often operate on tight power budgets, the algorithms must be sufficiently "lightweight" to run on a small, onboard computer with limited computational power.

In the last decade, artificial intelligence (AI) has revolutionized computer vision. Given sufficient training data, AI models can detect and classify objects in images more accurately than humans and without tiring. Numerous AI models trained on large, public datasets are openly available under permissive licenses. While typically trained on images captured in terrestrial environments, these models can readily be re-purposed for maritime environments by re-training on custom datasets. They learn to recognize ships, buoys, or even breaching whales, instead of cars, bicycles, or street signs.

However, these AI models typically detect and classify objects one video frame at a time without considering preceding frames. (This is particularly the case for the lightweight models suitable for small computers.) Thus, such models have no concept of time and do not provide information on object identity and motion. For this, a tracking algorithm capable of correlating objects between frames is needed.

In this short article, we highlight unique challenges encountered in applying tracking algorithms to the maritime environment and discuss solutions being developed at Open Ocean Robotics (OOR), a Canadian company producing and operating rugged, solar-powered USVs for a variety of applications.

OOR's DataXplorer™ is a small USV equipped with visual and thermal video cameras (Figure 1). Mounted on fixed supports about 1 m above the water surface, the cameras provide a 360° view of the USV's surroundings. The onboard computer allows in-situ, real-time processing of the video streams. Owing to the USV's small size, waves on the sea surface induce rapid and large camera motion which must be corrected to correlate objects between frames – a task that is further complicated by the low video-frame processing rates possible on a power-constrained computer.

In terrestrial settings, edge-detection algorithms are often used to correct for fast, small-amplitude camera motion. However, on the ocean, there are few, if any, fixed features to allow for such corrections. Instead, we use an inertial measurement unit (IMU) sensor to correct for large and small-amplitude motion. As illustrated in Figure 2, this approach allows us to stabilize the horizon and determine the azimuth of detected objects. Accurate

Figure 1: The DataXplorer uncrewed surface vehicle.

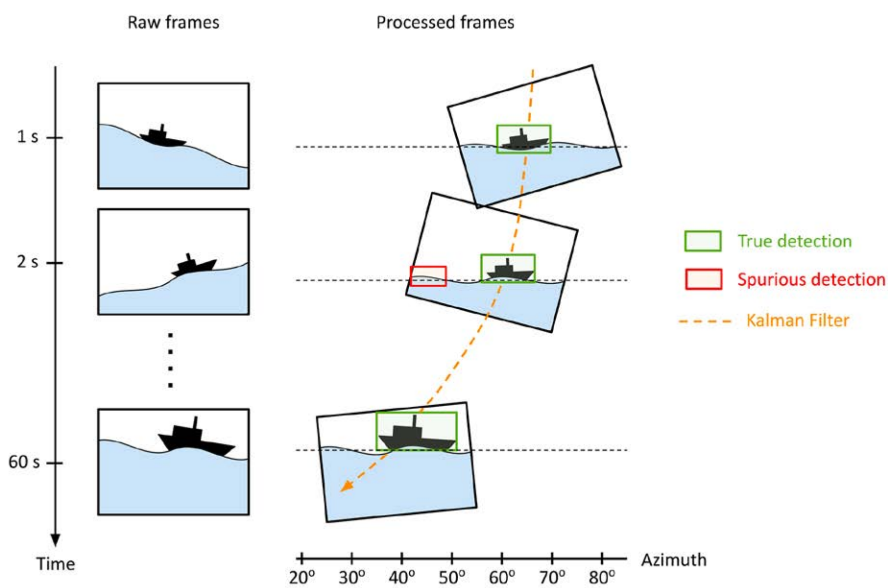

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Figure 2: Computer vision algorithm: inertial measurement unit (IMU) sensor data are used to stabilize the horizon and determine the camera azimuth. An AI model detects and classifies objects on a frame-by-frame basis. Finally, object motion is modelled using a linear Kalman Filter, allowing objects to be tracked across frames and helping reject spurious detections.

synchronization of video streams and IMU data at a 10 ms timescale, or better, is essential to yield satisfactory results.

To detect and classify objects, we use an off-the-shelf you only look once (YOLO) model, pre-trained on the public common objects in context (COCO) image dataset and re-trained on our own custom dataset which contains over 7,000 images acquired during DataXplorer missions under varying conditions of light, sea state, etc. For every processed frame, the YOLO model draws bounding boxes around detected objects and assigns them to one of several categories.

Once camera motion is corrected and objects are detected, we use a simple, linear Kalman filter to model the change in object position and apparent size between frames. Specifically, we consider the object's azimuth and height of its bounding box as we expect both quantities to change gradually with time. As illustrated in Figure 2, the Kalman filter allows us to correlate objects between frames and helps reject spurious detections thereby reducing the false alarm rate. The Kalman filter has a small number of adjustable parameters which must be carefully chosen to ensure optimal performance in a maritime environment.

The tracking algorithm described above is currently being tested in the field with promising early results. Meanwhile, we are also exploring more advanced methods for correlating objects between frames, e.g., using features implicitly learned by the AI model to quantify the similarity in "appearance" of two detected objects.

Computer vision for small USVs is a nascent and quickly growing field, now with a dedicated conference series, The Workshop on Maritime Computer Vision (MaCVi). At Open Ocean Robotics, we are uniquely positioned to contribute to the advancement of this field. As detailed in this short article, our latest efforts are focused on object tracking, a key step to achieving autonomous navigation.

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