An AIS-Based Site Planning Method to Help Minimize Collision Risk during Marine Autonomous Surface Craft Deployments

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ABSTRACT

Marine autonomous surface crafts (MASCs), or unmanned surface vehicles (USVs) as their precursors have traditionally been known, could cost effectively advance spatiotemporal coverage and resolution capabilities for oceanographic sampling in coastal and estuarine settings, if deployed for long durations (from days to weeks). Site planning for such deployments balances scientific goals against operational risk of collision avoidance (CA) maneuvers required by the MASC during encounters with other vessels. A method is developed and demonstrated in this paper, using archived Automatic Identification System (AIS) vessel tracking data, to quantify such potential encounters of a MASC on a repeat-transect survey. The demonstration site is Rhode Island Sound, where average vessel track frequencies are shown to range from about 8 to 0.01 or less per day, from inshore shipping lanes to areas farther offshore, respectively. Encounters per month ranged from 24 to 1 for increasingly offshore locations, based on a MASC repeatedly traversing an 18-km transect at an average speed of 2.5 m s\(^{-1}\) (\(-5\) kt) over a one-month summer period and stopping at each of 10 equispaced stations in one direction to sample for 10 min. Crude estimates of non-AIS vessel traffic suggest total encounters (with vessels equipped by AIS or not) up to 3–4 times higher. The method can be applied anywhere AIS data are available and is generalizable to any survey configuration. It facilitates investigating sensitivity to choices of transect location and sampling configuration parameters, providing crucial information to guide deployment planning for a given level of confidence in CA capabilities of the MASC.

1. Introduction

Capabilities of marine autonomous surface crafts (MASCs), or unmanned surface vessels (USVs) as their precursors have traditionally been known, continue to advance [see, e.g., the survey included in Yang et al. (2011); the review by Motwani (2012); and Savitz et al. (2013) for military applications]. The potential for long-duration (from days to weeks) unattended deployments could open up cost-effective oceanographic data collection with coverage and resolution, both spatially and temporally, that has not previously been attainable by any platform in busy coastal waters. Bringing this to fruition hinges on technologies for collision avoidance (CA). Autonomous onboard navigation systems capable of detecting and avoiding other vessels have been demonstrated in simulations (e.g., Filimon 2013) and in controlled field tests (e.g., Benjamin et al. 2006; Kuwata et al. 2014). For operational safety MASCs will rely on the Automatic Identification System (AIS), which monitors ship traffic from marine vessels, ground stations, and aircraft using very high frequency (VHF) radio (Arroyo 2011), and is required on commercial vessels over 300 tons and all passenger vessels. Vessel information, such as position, speed, and heading, is transmitted and recorded in real time. Equipping a MASC with AIS is straightforward and helps ensure its detection by other AIS-equipped vessels, and vice versa.

This paper presents a method applicable to MASC deployment planning in the context of balancing the goal to limit restrictions on scientific sampling against the need to minimize operational CA risks. First, patterns of historical vessel traffic in a region are analyzed...
using archived AIS data. This knowledge is then used to quantify the potential for MASC encounters with other vessels, as a function of the sampling parameters that define the MASC survey. While the method has general applicability, it is demonstrated here for the setting (Fig. 1) of Rhode Island Sound (RIS), where initial deployments of the Surveying Coastal Ocean Autonomous Profiler (SCOAP; Codiga 2015) MASCs are planned, using SCOAP-based survey sampling characteristics.

2. Methods and observations

a. Vessel track frequency from archived AIS data

Publicly available archived AIS data from 2009 and 2010 were obtained online (www.marinecadastre.gov), as developed by the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration, in the form of ArcGIS file geodatabases (Taylor and Stein 2011). Vessel traffic density was quantified in terms of track frequency (TF), defined as the average number of tracks per day within a specified grid area during a specified time period. Based on comparisons to 1- and 0.25-km treatments (not shown), a grid resolution of 0.5 km was determined most suitable. TF was computed for individual month time periods first, then groups of three months were averaged to produce seasonal TF (winter = January–March, spring = April–June, summer = July–September, and fall = October–December). All months included sampling every day except June 2009, which had only 4 days sampled; when the seasonal means were computed from monthly results, they were weighted based on the number of days sampled during each month. For clarity the quantity plotted (Fig. 2) is \( \log_{10}(TF + c) \), where \( c = 1 \times 10^{-5} \) is a small constant offset to prevent unbounded values where TF is zero. For example, values of -1, 0, 1, and 2 for \( \log_{10}(TF + c) \) correspond to a TF of 0.1, 1, 10, and 100 ship tracks per day, respectively.

b. Potential encounters of MASC with AIS-tracked vessels

Potential encounters that a hypothetical MASC doing repeat-transect sampling would have with historical AIS vessel tracks were determined as follows. First, the repeat-transect track of the hypothetical MASC,

\[
x^MASC_i = x^MASC(t_i), \quad \text{for} \quad t_i = t_o + i\Delta t, \quad i = 1, \ldots, n,
\]

where \( x^MASC \) is the vector latitude–longitude location and \( t_o \) is the initial time, was determined to \( \Delta t = 0.5 \)-min temporal resolution. This required specifying the MASC speed, the location and length of the transect, the number of stations along the transect, the station-keep duration at each station, the start time, and the total deployment duration. The baseline case was a one-month duration deployment during July 2009 with the MASC moving at 2.5 m s\(^{-1}\) (~5 kt) along an 18-km-long transect (Fig. 1) in RIS stopping, while traveling in the eastward direction only, for 10 min at each of 10 equipped stations. These repeat-transect sampling parameters are based on the design goals for SCOAP (Codiga 2015).

The historical AIS ship tracks during the interval of time spanned by the hypothetical MASC track are

\[
x^SHIP_i = x^SHIP(t_{ki}), \quad \text{where} \quad j = 1, \ldots, m \quad \text{is the index of the ship track and} \quad k = 1, \ldots, p \quad \text{is the index of the AIS time stamps} \quad t_{ki} \quad \text{along it. For each time step} \quad i \quad \text{on the MASC track, all} \quad p \quad \text{time stamps of each of the} \quad m \quad \text{ship tracks are searched for fixes that meet both criteria,}
\]

\[
|x^SHIP_{ki} - x^MASC_i| < X_{thresh} \quad \text{and} \quad |t_{ki} - t_i| < T_{thresh},
\]

and therefore passed within a threshold distance \( X_{thresh} \) (baseline case 400 m) of that MASC location within a corresponding threshold time interval \( T_{thresh} \) (baseline case 2 min). All such fixes, which represent a potential encounter between the MASC and the ship and are presumed to require the MASC to perform CA maneuvers, are compiled. In a small number of cases, multiple consecutive fixes on the ship track meet the thresholds; they are counted as a single encounter.

To investigate sensitivity to the transect location, the baseline case was repeated at all five transects (A–E;
Fig. 1) for the month of July 2009. To investigate sensitivity to seasonal and interannual variations, the baseline case was repeated at transect A using one-month intervals in January, April, July, and October of 2009 and 2010. To investigate sensitivity to station-keep duration, the baseline case for transect A was repeated for 0-, 20-, and 30-min station-keep durations. To investigate sensitivity to MASC speed, the baseline case for transect A was repeated for MASC speeds 1.5 and 3.5 m s\(^{-1}\). Two calculations investigated sensitivity to threshold values: the baseline case at all transects but using \(X_{\text{thresh}} = 800\) m with \(T_{\text{thresh}} = 4\) min and using \(X_{\text{thresh}} = 200\) m with \(T_{\text{thresh}} = 1\) min.

3. Results

Shipping lanes, with a TF of five to eight tracks per day in all seasons, are the most prominent feature in seasonal TF maps (Fig. 2). Secondary routes (including a ferry passage between Block Island and Point Judith, Rhode Island) have heavier traffic (five to eight tracks per day) in summer than in winter (one to three tracks per day). Some routes leading to/from the southwest have about 0.5–1 tracks per day. Elsewhere, tracks are generally dispersed geographically, with a TF in the range of 0.1–0.01 tracks per day, as low as one ship every 10–100 days. During spring and summer, the geographic extent of low but nonzero TF values outside the main shipping lanes is enhanced compared to fall and winter.

The number of MASC encounters with historical AIS vessel tracks was 24, 6, 6, 1, and 1 (Fig. 3a) for one-month deployments along the five transects A–E in Fig. 1, respectively, using baseline parameters (July 2009, 2.5 m s\(^{-1}\) speed, 10-min station-keep duration, \(X_{\text{thresh}} = 400\) m, \(T_{\text{thresh}} = 2\) min). Although the common knowledge that vessel traffic in and around RIS generally decreases offshore leads to a qualitative expectation of fewer encounters at transects farther southeastward, the method has quantified this decrease in encounter frequency, so generating valuable information for purposes of risk assessment.
Seasonal and interannual variability in encounter numbers is pronounced, as illustrated by results for the months of January, April, July, and October in 2009 and 2010 at transect A (Fig. 3b): the mean is 14.6 encounters with a standard deviation of 6.3 encounters. Peaks are in the summer of both years, consistent with the above-mentioned TF descriptions and the higher baseline case encounter numbers during July.

The influence of station-keep duration (Fig. 3c) and MASC speed variations (Fig. 3d) on the number of encounters is comparable to the standard deviation of the seasonal variability. These variations are considered random, due to the low number of encounters, as opposed to being evidence that there is a mechanistic reason why the 10-min station-keep duration and 2.5 m s$^{-1}$ speed yielded the highest numbers of encounters. Sensitivity to the start time was not explicitly investigated, but the range of MASC speeds studied, together with the fact that each deployment includes a large number of repetitions of the transect, ensures a broad range of start times for individual transect crossings during the deployment; this suggests that sensitivity to the start time should be no larger than that found for the MASC speeds. When the encounter thresholds $X_{\text{thresh}}$ and $T_{\text{thresh}}$ are increased and decreased (to 800 m with 4 min and 200 m with 1 min, respectively) the numbers of encounters increase and decrease, as expected (Filimon 2013); the maximum and minimum values are 40 and 13, respectively, at transect A, with a pattern at the farther offshore transects that is generally similar.

4. Discussion

A recognized operational constraint on MASC deployments is that Coast Guard (CG) approval is likely infeasible for a repeat-transect sampling across established shipping lanes, such as some transects in this study (notably A and B; Fig. 1). Nonetheless, the RIS setting and specific transects used serve the purpose of demonstrating the method, which is general and suitable for application anywhere archived AIS data are available. AIS data availability is increasing, a trend that is anticipated to continue and intensify.

The method is applicable to operation of a MASC on a fixed repeat-transect route, with a preconfigured combination of sampling parameters (speed, station-keep
duration, etc.) that will not change during the deployment, except as required for CA maneuvers, which are presumed to be a small fraction of the deployment time. It is thus not intended to be comparable to more sophisticated route planning methods—for example, those that incorporate real-time sampling information to adaptively optimize the route (e.g., Svec et al. 2011)—but rather could be a useful complement (e.g., for initial site selection based on archived information) to such approaches.

A limitation of the method is that it cannot address potential encounters with vessels not equipped with AIS. This includes primarily smaller, recreational vessels and certain commercial fishing vessels. It also includes vessels equipped with receive-only AIS systems, from which data are neither transmitted nor archived. Consequently, estimated numbers of potential collision encounters generated by the method are lower bounds for possible encounters with all vessels (AIS equipped or not). A rough approach to estimating total potential encounters (with both AIS and non-AIS vessels) is to scale up the AIS-based results under the crude assumption that geographic and temporal distributions of non-AIS vessels are similar to those of AIS vessels. The opinion of certain experienced RIS mariners (e.g., P. LeBlanc, Safe/Sea Boat Towing and Marine Salvage, 2013, personal communication) is that about 40%–70% of vessels are non-AIS, with the higher percentages in this range applicable during summer when recreational boats are most numerous. The AIS-based results for the summertime (July) baseline case are similar to those of AIS vessels. The opinion of certain experienced RIS mariners (e.g., P. LeBlanc, Safe/Sea Boat Towing and Marine Salvage, 2013, personal communication) is that about 40%–70% of vessels are non-AIS, with the higher percentages in this range applicable during summer when recreational boats are most numerous. The AIS-based results for the summertime (July) baseline case (Fig. 1) correspond to total potential encounters (with both AIS and non-AIS vessels) of approximately 80 and 3 per month, respectively. Despite its obvious limitations, including the inaccurate assumption that AIS and non-AIS vessels have the same spatial and temporal distributions, this approach is a starting point to help address the issue of non-AIS vessels.

5. Conclusions

A method has been developed and demonstrated, using archived AIS records, to help quantify the risk of encounters with vessel traffic for a MASC performing a repeat-transect oceanographic survey (Fig. 1). The first stage is to describe and quantify geographic and temporal patterns in vessel traffic (Fig. 2). Next, this information is used to determine the number of encounters a MASC has (Fig. 3) with archived vessel tracks, based on a given set of repeat-transect configuration parameters and two threshold parameters that define an encounter. Results for hypothetical transects in RIS have quantified the frequency of CA encounters of the SCOAP MASC during a summer deployment, as a function of the MASC sampling parameters. The method is sufficiently general to be applied in any region for which historic AIS information is available, and it can straightforwardly be adapted to arbitrary survey configurations.

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