Active Drifters: Sailing with the Ocean Currents

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I. Introduction

The ocean is a highly dynamical system in both temporal and spatial dimensions, which makes oceanographic and marine biological studies challenging. One important class of tasks for gaining deeper understanding of the ocean is the tracking of an advection of ocean phenomena, such as algae blooms or oil spills, caused by ocean currents. One approach to this tracking task is to tag a current through passive Lagrangian drifters.

A *drifter* is a buoy that consists of a surface float, i.e., a sealed container floating on the surface, and a drogue, which is fixed at a certain depth. The drogue plays basically the role of an underwater "sail" that makes the drifter travel passively with the ocean current at the corresponding water layer (see Fig. 1). Traditionally, a drifter acts as a simple reference point which takes no or just a small part of measurements. More measurements can be carried out with the help of an additional active vehicle like a ship or an autonomous underwater vehicle (AUV) [1]. However, this approach comes with the disadvantage of increased complexity and significant financial expenses due to high ship and AUV operating costs. This may affect the scope of scientific studies and lead to shortened temporal domains and sacrifices in the spatial resolution of collected data. Thus, oceanographers and marine biologists can profit from a simple and inexpensive platform which nevertheless offers enough autonomy to carry out long missions and make decisions actively. Such a platform does not have to be capable of executing rapid maneuvers; agility can be traded off for endurance.

For this reason, we suggest to turn a traditional passive drifter into an *active drifter*. By actuating the drogue to adjust it in depth (see Fig. 1 on the right), the drifter is capable of exploiting the stratification of the ocean, i.e., it can actively select from the different layers of ocean currents, each of which potentially provides a different current vector. This enables the system to 1) measure the vectors of ocean currents directly at varying depths on site, and 2) obtain (limited) control capability.

Recently, a few alternative active drifter systems have been presented. Following a similar idea to ours, [2] introduces a small profiling drifter that can raise and lower its drogue via a winch, and [3] uses a free-floating drogue vehicle which is capable of submerging by a change in buoyancy. Based on a similar principle, larger and more complex Lagrangian profilers can also be operated as active drifter systems [4, 5].

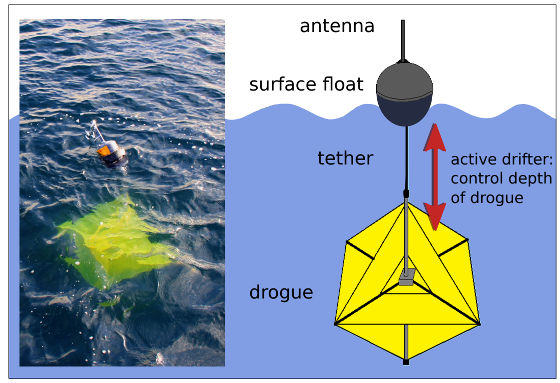

Fig. 1. Passive and active drifters. Left: A prototype of our passive drifter system, which was deployed in the Southern California Bight to measure the vectors of the ocean currents locally. Right: The schematic shows the main components and the mode of operation of a passive as well as an active drifter.

II. Problem Definition

Any underwater or surface vehicle operating in the ocean is exposed to ocean currents. The currents are generally treated as noise which perturbs the vehicles' trajectories. In the case of underactuated and rather passive systems like passive or active drifters, the currents however act as the main driving force and can be seen as the primary component of a controller. In order to anticipate the way the vehicles are affected by the currents and design a control policy that actuates the drogue of an active drifter to reach a desired destination, it is essential to obtain good estimates of the ocean currents at all times.

Due to the large spatial scale of the ocean, it is hard to acquire such estimations at decent resolutions from standard ocean measurement tools, such as moorings, HF radars and satellite data, solely. Another route that has been explored in recent works (e.g., [5]) is to utilize predictions based on ocean models, for example, using the Regional Ocean Modeling System (ROMS), possibly enhanced by the additional assimilation of real data (see http://ourocean.jpl.nasa.gov/). However, many ocean phenomena are not yet completely understood, and as we show in the next section, these models are often not very accurate and have a rather low resolution. In order to estimate the current vectors directly on site, our approach tries sampling the vectors locally at different drogue depths. For example, in our present drifter prototype, the vectors can be measured via the drifter's motion from two successive GPS locations. The approach does not require any prior information about the ocean, which may simplify the deployment of the system and potentially enable its use in arbitrary areas of the ocean.

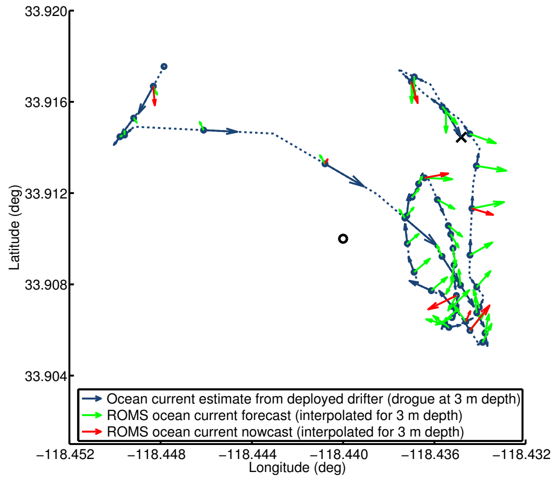

Fig. 2. Comparison of ocean current measurements and ROMS predictions: the current forecasts (green vectors) and nowcasts (red vectors) are plotted along the measured trajectory and estimated currents of the deployed passive drifter (blue dotted line and blue vectors). The black circle in the middle represents the center of a cell of the grid that underlies ROMS.

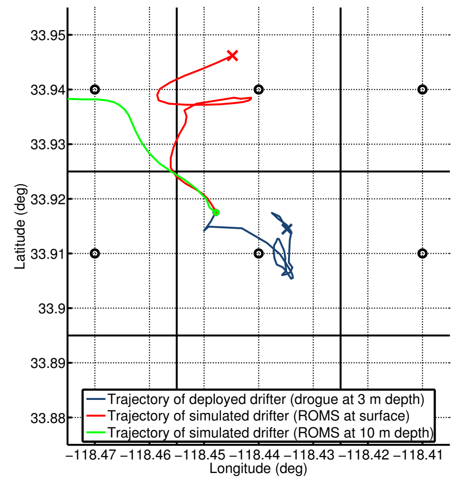

Fig. 3. Comparison of ocean current measurements and ROMS predictions: trajectories generated by the "drop a drifter" web page, and the real trajectory of the drifter deployed in the Southern California Bight.

III. Predictions and Measurements of Currents

In order to evaluate how well real and predicted ocean currents match, we deployed a passive drifter with drogue fixed at 3 m depth in the Southern California Bight near the coast of Los Angeles over 2 days (see Fig. 1 on the left). We operate at a local scale within kilometer range, which is below the minimum resolution of ROMS of 3 km $\times$ 3 km; hence a few relevant ROMS data points are available only. Although ROMS is a valuable tool at larger scales, the recorded data of Fig. 2 indicate that locally ROMS predictions often deviate significantly from the measured currents[1]. This is especially well demonstrated by Fig. 3, which depicts the trajectory followed by the deployed drifter and the trajectories predicted by ROMS[2]. More detailed analysis of the data from the deployed drifter (see Fig. 4 and Fig. 5) shows that ROMS predictions and the real currents have weak positive correlation in the direction (the correlation coefficient is equal to 0.36) and weak negative correlation in the absolute values (the correlation coefficient is equal to -0.35). We see that as an indication of relatively poor consistency between ROMS predictions and the real in situ measurements. At the same time, nowcast and forecast predictions seem to be consistent with one another, i.e., they are highly correlated.

IV. Navigating an Active Drifter

Given the above results of our field experiments, we aim at an approach that does not rely on ocean current predictions primarily, which is different from most former related works ([2, 5] among others). The idea is to estimate currents in situ

[1]This presents an interesting direction for future research on how to combine on-line data from active drifters with ocean models like ROMS to further improve drifter navigation, as well as the ocean models themselves.

[2]The trajectories are generated using the "drop a drifter" web page. See http://www.cencoos.org/sections/models/roms/ca/drifter/.

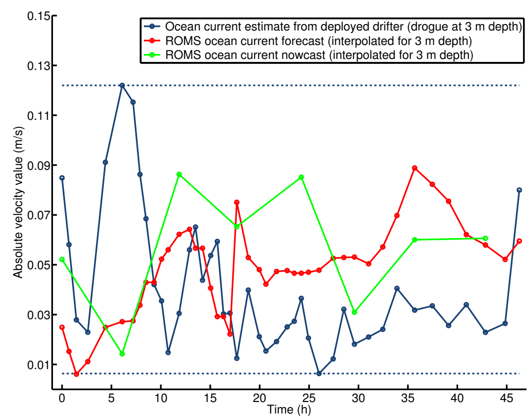

Fig. 4. Comparison of ocean current measurements and ROMS predictions: absolute values of the ocean current velocity vectors.

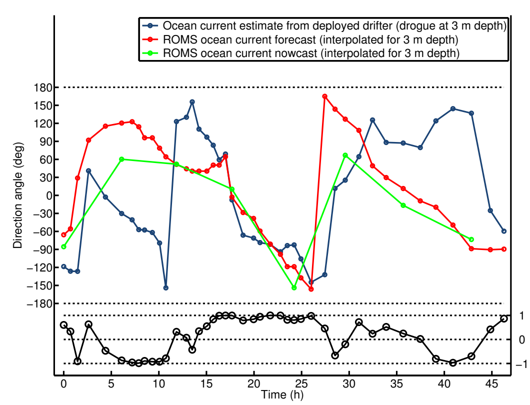

Fig. 5. Comparison of ocean current measurements and ROMS predictions: direction angles of ocean current velocity vectors. The bottom part displays the cosine of the angle between the vectors of the ROMS forecast and the measurement, which visualizes their alignment (1: the same direction, 0: perpendicular, -1: opposite direction).

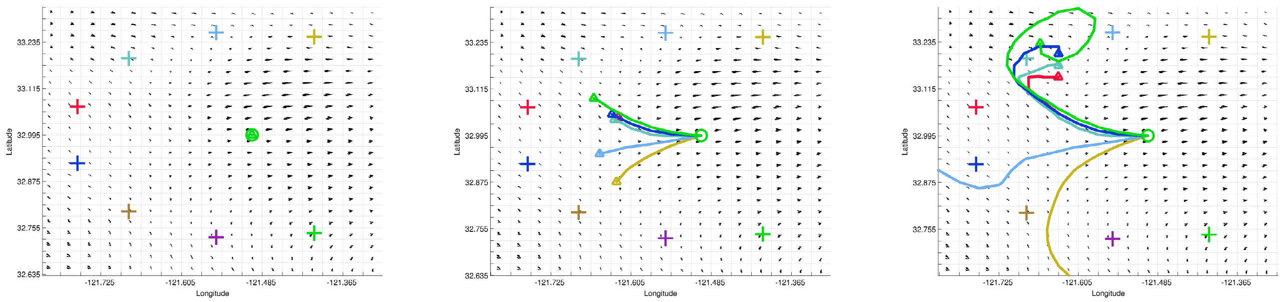

Fig. 6. Simulated trajectories (colored curves) of passive drifters with varying drogue depths starting from the same location (green circle). From left to right, the pictures depict the evolution of trajectories over time (0 days, 2 days, 30 days correspondingly). The colored crosses represent goal targets. The passive drifters managed to hit only 1 target out of 8. The simulation is run in a static ocean current field generated from ROMS data.

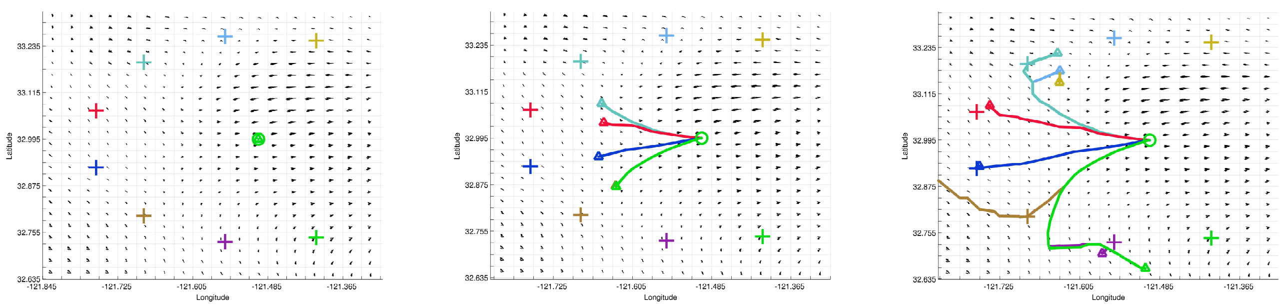

Fig. 7. Simulated trajectories (colored curves) of active drifters starting from the same location (green circle). From left to right, the pictures depict the evolution of trajectories over time (0 days, 2 days, 30 days correspondingly). The colored crosses represent goal targets. The color of the target corresponds to the color of the drifter it was assigned to. The active drifters managed to hit 5 targets out of 8. The simulation is run in a static ocean current field generated from ROMS data.

and use these estimates to design a reactive control policy that actuates the drogue to select a favorable current to drive the active drifter toward the destination. One can apply the following control policies, which all use the measurements of the currents at the present drifter position[3]:

- *Maximum projection (PRJ)*: Select the current whose vector produces the largest projection onto the axis of sight, which is the axis originating at the present position of the drifter and passing through the destination.
- *Minimum distance (DIST)*: Select the current for which the prediction of one step (or multiple steps) ahead results in a new drifter position with the smallest predicted distance to the destination.
- *Minimum angle (JF)*: Select the current whose direction is "closest" to the axis of sight, i.e., with the smallest angle between the current vector and the axis of sight. A similar idea was proposed by [4].

Since drifters do not have their own propulsion, the controllability of active drifters depends heavily on the set of currents present at a location. As shown in [4], current vectors of different depth must span the plane positively everywhere to guarantee controllability of the drifter. Although an active drifter is only partially controllable and cannot reach every destination, it usually still performs better than a drifter with no control. For instance, Fig. 6 and Fig. 7 show the situation where 7 out of 8 destinations are unreachable for passive drifters (independent of their drogue depth), but the active drifter (here with minimum angle policy) manages to hit at least 5 of them.

Fig. 8 presents a comparison of the performance of the three different control policies using the minimum distance to a destination as a metric. The simulations were carried out in a dynamic ocean current field generated from ROMS data. The simulations show that the DIST and the PRJ controllers have very similar performance and statistically perform slightly better than the JF control policy. At the same time, all three controllers result in significant increase in performance compared to a passive drifter with a random choice of depth of the drogue. In this particular simulation, we observed 2 to 4 times better performance compared to a drifter with no control (a passive drifter) with the given metric.

[3]Although we do not use ROMS predictions in the control policies, we rely on ROMS in our simulations as a generator of realistic ocean currents.

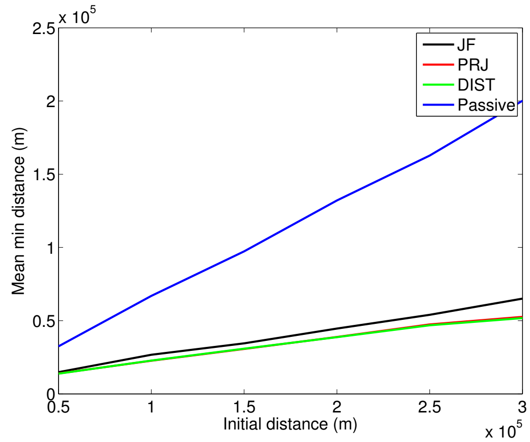

Fig. 8. The mean of the minimum distance to a destination vs. initial distance to a destination. Each graph is made of 6 discrete data points with different initial distances. Each point is the mean over 1000 simulated trials with the same initial distance. In each trial, a drifter was given the task to go from a random initial point to a destination picked randomly, but with the predefined distance between them. The minimum distance achieved by the drifter in each trial was recorded. The duration of one trial is 180 days.

V. Conclusions and Future Work

Due to underactuation of the drifters and the ocean's chaotic and highly unpredictable dynamics, the problem of predicting and controlling the trajectories of drifters in the ocean is challenging. In our work, we show that existing ocean models oftentimes do not provide sufficient accuracy, which motivates us to explore an alternative approach for the control of active drifters, namely control based on in situ measurements of the ocean currents.

Our ongoing work looks at minimum distance control policies with multi-step prediction horizon, and studies *multi-drifter systems* and the collaborative tasks of staying together, tracking, aggregation, dispersion and coverage. We believe that the control of single and multiple active drifters offers an interesting novel research direction.

References

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