MULTIVEHICLE CO-OPERATION IN A TRICKY AND INTERESTING SCENARIO USING IVP AND A CANADIAN RUMINANT - A PROPOSAL

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Abstract. The goal is to highlight the efficacy of multi-objective optimisation (in particular the IvP architecture) in a non-trivial multi-vehicle scenario.

1. Scenario

We are motivated by the following scenario:

- Two autonomous underwater vehicles $V_\oplus$and $V_\ominus$are in mutual collaboration together.
- Vehicle $V_\ominus$is charged with performing an at-depth survey using only DVL and heading sensors. The accuracy of its position estimate will degrade with time.
- Vehicle $V_\oplus$is charged with two tasks - shuttling information from $V_\ominus$to the surface and providing (via mutually planned proximity) positional information to $V_\ominus$.
- Vehicle $V_\oplus$is able to surface (but in doing so leaves $V_\ominus$alone) and obtain a GPS fix. On the surface it can relay cargo data (from $V_\ominus$) to a base station. When $V_\oplus$dives, the error in its own position estimate starts to increase. One might think that ideally it makes a rendezvous with $V_\ominus$in the shortest amount of time- however depending on its state, $V_\ominus$may or may not consider it advantageous to rendezvous....(more on this later).
- During a rendezvous $V_\oplus$broadcasts its current position, $x_\oplus$, via an acoustic modem.
- Vehicle $V_\ominus$figures out its position in the following way: it hears $V_\oplus$transmitting its position, $x_\oplus$. It then instigates a two-way ranging "ping" to measure the distance between them, ${}^\ominus r_\oplus$. Vehicle $V_\ominus$then takes its position to be $x_\oplus$ with a circular error bound of ${}^\ominus r_\oplus$.
- Of course, the true position of $V_\ominus$actually lies on a sphere of radius ${}^\ominus r_\oplus$ around $x_\oplus$. However the idea here is to examine action selection as a function of time varying sensor / navigation conditions and *NOT* fancy navigation techniques like moving-baseline.
- The precision of $V_\ominus$'s navigation fix is clearly improved if it manages to be close to $V_\oplus$at the time of a position broadcast. The question now is how can $V_\ominus$plan to achieve this?. Two options present themselves:
  1. $V_\ominus$can dead-reckon (using its own, ever-degrading, position estimates)
  2. $V_\ominus$can instigate multiple two way ranges and crudely estimate the trajectory of $V_\oplus$and hence plan an intersect course.

Key words and phrases. Tricky,Fun.

The second of these is quite interesting - if $V_\ominus$is unsure of its own current trajectory it may be advantageous to stop moving and simply "ping" $V_\oplus$to get a good fix on the direction. It may also be the case that the probability of hearing the modem transmission from $V_\oplus$is increased when $V_\ominus$is in a quiescent state.

- The use of acoustic modems brings a welcome complication — they only have a fixed transmission distance - move too far away and telemetry can't be heard, really "take a walk" and the two way pinging will fail. That means $V_\ominus$is utterly screwed and must abandon its own mission.

2. More on the scenario by M.Benjamin

Three things I wanted to touch on (1) vehicle modes, (2) Searching conducted by $V_\ominus$, and (3) position updating between the two vehicles. I hit 2/3 for now...

2.1. **Modes for the two vehicles.**

The two "modes" are 1) rendevouz mode, and 2) non-rendevouz mode. In rendevouz mode, the $V_\oplus$vehicle will make itself available to rendevouz with the $V_\ominus$vehicle and assist in localization. In non-rendevouz mode, the $V_\oplus$vehicle will simply not be available - its action during this mode may not be important. However, in non-rendevouz mode, $V_\ominus$will be diligently searching a prescribed area. It is assumed that the two modes will occur at times agreed upon by the two vehicles, and that an internal clock on board is sufficient to maintain this coordination. For example, repeated 20 minute cycles with the first 6 minutes constituting "rendevouz" mode. (A fixed schedule may be appropriate, but we could also consider an arrangement where $V_\ominus$request a schedule more to its liking depending on the situation).

It is assumed that, for $V_\ominus$, full search of the area will require multiple iterations of mode cycles. At the very least, two vehicle behaviors will be written for $V_\ominus$- one for searching the search region, and one for ensuring that $V_\ominus$is able to rendevouz with $V_\oplus$. It is likely that, at times the two behaviors will be mutually exclusive, and at times they will *not* be mutually exclusive. It is this relationship that will make action selection non-trivial.

This leaves two areas to drill down on: what constitutes search for $V_\ominus$and how is the rendevouz and position fixing done?

2.2. **Searching a polygon.**

The basic idea is that a vehicle, $V_\ominus$, is tasked to search an area given by a rectangle, or polygon, or set of areas. WLOG, let's say its a single rectangle, and that it is composed of grid elements as shown below in Figure 1.

2.2.1. *Search metric and stopping condition.*

The goal for $V_\ominus$is to "maximize" search of this area, where the metric for mazimization, and the stopping condition, are not yet determined. The two general cases are:

(1) The vehicle must satisfy a full-search condition, and the metric is the time needed to do so, or
(2) The vehicle has a fixed time of operation (batterly life) and the metric is quality of search achieved in that time window.

For practical purposes, it perhaps makes more sense to let *time* be the stopping condition, and let search quality be the performance metric. Now lets consider different possibilities for the notion of "search quality".

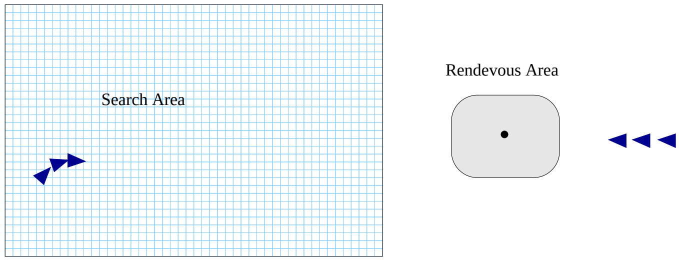

FIGURE 1. The $V_\ominus$ vehicle is tasked with searching an area given by a rectangle. The rectangle is composed of discrete elements, and the goal is to maximize the search coverage of the grid. Additionally, a "rendevouz area" is agreed upon for the two vehicles to rendevouz and update the position estimate for $V_\ominus$. The rendevouz area may or may not be distinct from the search area.

2.2.2. *Search quality notions.* Settling on a notion of "search quality" boils down to a) making some tie-in to a "real-world" problem such as searching for an artifact(s) or mapping the seabed, and b) reflecting the notion of (a) in the following two questions:

(1) What affects the *local* metric of a search unit as a vehicle passes through? Speed? Position uncertainty? Having been there before?
(2) What is the *global* metric at the end of the mission for combining the locally stored metrics of individual units into a singular metric of overall mission effectiveness?

For example the following is the simplest search metric I can think of: "the number of elements visited within the alloted time". This implies that the speed at which the vehicle moves through an element does not matter, and it does not reward revisiting a element. Simple, but does it reflect a real-world problem? It also doesn't address position uncertainty.

I think we should discuss the issue of the real or pseudo-real world problem we want to focus on and let that determine our metrics, which will in turn determine the vehicle behavior implementation. Perhaps Matt, you have some ideas regarding the Arctic mission you mentioned in Elba?

In the meanwhile, I will assume a variation of the simple metric above: A visit to an element will associate a score between $0 \ldots 100$ with the element. The score will be 100 if the position uncertainty is zero, and closer to 0 as the position uncertainty grows. And barring Paul's implementation/simulation of dead-reckoning drift, I will assume a linear growth of a single scalar variable `position_uncertainty` as time grows. Revisits to an element will reflect the max score of any of the visits. Thus revisits may be encouraged, but will depend on what has been achieved in past, and what the anticipated value of `position_uncertainty` will be on a hypothetical re-visit.

2.3. **How the two vehicles will Rendevouz.**

3. Problem Statement

Given the above scenario what behaviours should be written that :

(1) Maximise the precision of $V_\ominus$'s survey?
(2) Maximise the size of the Survey that $V_\ominus$can undertake before survey quality falls below an acceptable metric?
(3) Maximise the data flow from $V_\ominus$to the surface via $V_\oplus$?
(4) How sensitive are these behaviours to their governing parameterisations? (hard but important)

4. Our planned approach

- We don't want to use AUVs - they are troublesome
- We are going to use MRB's Kayaks in the Chuck with modems (loaned for a few days) dangling from their under-sides.
- Without loss of generality, we are going to have the vehicles fake dilution of precision (DOP) in location estimation as time increase by adding a Brownian drift to GPS-derived position. Alternatively we could really simulate a DVL and integrate GPS velocity measurements.
- Anyway, the point is we can make life easy for ourselves by having resident experiment marshalling behaviours running which keep the vehicles from really getting lost by using uncorrupted GPS position fixes.

5. Work Packages

(1) Draw up a linear progression of scenarios. (we should have high confidence that the fist of these will work out-of-the-box on day1 on the river)
(2) Draw up a list of un-written source code - things we need. For example the code that takes a sequence of two way ranges and figures out an intersect course.
(3) *SIMULATE SCENARIOS*
(4) integrate modems
(5) Matt finish his wizzo modem driver
(6) Mike write the basic behaviours
(7) PMN write a position diluting sensor (which is actually a GPS)

6. Concerns

(1) Too many parameters controlling behaviours? Too bespoke?
(2) Important to liase with jjl and keep him very much in the loop. This is NICOP funded work and must not interfere with Johns planned research. Mikes Kayaks are also only operational because of Johns input/position so its important he is on board with our plans. Hopefully these sets of experiments will mature the IvPHelm and increase its utility to Johns work. This needs to be complementary not adversarial and in no way crowding.

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