Towards Distributed, Behaviour-Based Trust for Autonomous Submarine Fleets

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Introduction

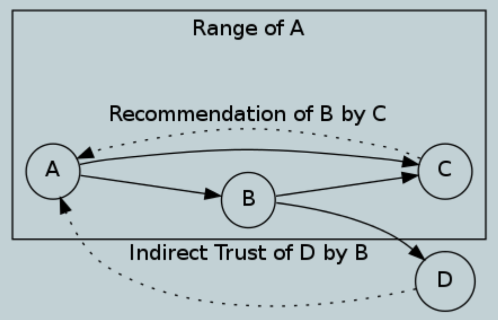
Aim of project: To use physical behaviours and observations to assess trust within a mobile, marine, ad-hoc network without wasting communications time / energy

- Small fleets of AUVs (*Autonomous Underwater Vehicles*) will be expected to operate in isolated environments.
- This requires an auditable sense of trust within the remote intra-fleet communications networks, incorporating
  - Communications Activity
  - Mission Suitability/Capability
  - Behavioural Monitoring
- The use of centrally coordinated trust models presents a single point of failure.
- Verifiably secure direct communications in marine environments are expensive and time consuming; therefore

Context Areas

- This Behaviour monitoring is the subject of the current work and touches on many areas
  - Distributed Trust
  - Grey-Theory Analysis
  - Anomaly Detection and Identification
  - Underwater Localisation
  - Flock Simulation
  - Collaborative Path Planning
  - Iterative Principal Component Analysis
  - . . . and more not yet covered

Trust



Trust is:

- an assessment of the future liklihood of an entities action upon request
- a belief on the reliability of an entitity
- based on both direct and indirect historical experience

Individual trust opinions are shared with the local neighbourhood, and apply to a range of activities:

- Transmission Relaying (Local and/or Backhaul)
- Position Relaying
- Reporting Accuracy

These Trust opinions also apply to extra-fleet entities, such as surface platforms, submarine comms links, and coastal stations, allowing the fleet to collaboratively form an opinion of these actors. In this contest, Trust is implied to be both that trust between nodes within a fleet, and the continuous assessment of trust of between the fleet and extra-fleet entities such as operators and fleet-commanders, to in theory provide an ongoing assessment of the liklihood of success of a particular missions.

Mission-Driven Behaviours

The simulation framework used enables abstract behaviours to be heuristically combined using desire-vector combination and normalisation.

Currently implemented Behaviours include:

- *Waypointing* - Attraction to a point or a chain of points, providing pre-described patrol networks
- *Surveying* - Fleets can be tasked to provide one-shot, or persistent coverage of an area of the environment
- *Dynamic Constraint* - Repulsion from a series of points, analogous to sea-borders or shipping lanes.

Potentially Explotable Behaviours not yet developed include:

- *Capacity Based Homing* - For instance for refueling or resupply, the fleet (or individuals within the fleet) can break away to a static or mobile *mothership* and return to the estimated fleet position
- *Dynamic Communications Maintence* - The fleet can adjust to changing communications environments by factoring metrics such as packet loss into flocking model, closing together in poor communications environments and expanding in good environments.

Simulation Framework

Bespoke Simulation framework consisting of three modules:

- `Aietes` : the original base behavioural simulator, performing agent-based modeling of the motions of AUV's within an environment
- `Bounos` : a collection of data processing and collation functions.
- `Ephyra` : a GUI visualisation (and later, control) system for both Aietes and Bounos

It is highly flexible, allowing for:

- Arbitrary node configurations (both in terms of physical and communications capabilities)
- Generically Based on the REMUS 100 configuration and physical model, but extendable to other dynamics
- Support for runtime and a-postori statistical analysis with numpy/scipy/pandas
- Componentized Behaviour network, with a Boidean flocking base

The intention of the framework is to provide a testbed for the development protocols to maintain trust within marine networks. This

will be made simple through the integration of the SUNSET emulation system that provides an abstraction layer between simulation and real-nodes, meaning that protocols derived from this framework will be directly integrated into existing platforms. It is intended that the

analytical toolkits developed (Bounos) will be environmentally agnostic, allowing for application beyond the marine space.

Proof Of Concept

- Using a simple misbehaviour such as a rouge AUV following the fleet (and the fleet rules) without knowledge of the mission specification as a Theoretical Proof of Concept allows for rigerous analysis of research options.
- Taking a selected metric (Inter Node Distance Deviation), it is shown that detection is possible and reliable (after a suitable stabilisation time.
- This metric is isolated from other analysed metrics as shown in Figure **??**, where INDD is the only consistently observable differentiating metric between normal behaviour and rouge behaviour.
- It is also shown that before stabilisation, it is nearly impossible to differentiate.
- Additional related metrics such as the Inter Node Heading Deviation (INHD) and the simple Speed of the nodes are slightly discriminating, but are not as consitent as INDD.
- All of the current metrics are real-time computed and require no a-priori knowledge of the fleet, but require a high degree of accuracy in the positional and (hence) velocity spaces.

Future Work

- PoC demonstrates that it is relatively simple to detect and identify misbehaving if an observer has all availiable data to a suitable degree of accuracy and timeliness
- Next steps are to develop a suite of misbehaviours and analyses to construct an agnostic trust framework, combining these multiple analysis metrics via Gray Theory so as to provide detection, discrimination, and identification of the full range of potential misbehaviour/failure states

Future Applications

- Due to the high communications, motion, and computation costs, and lack of external location reporting (*e.g. GPS*), behavioural analysis in the marine environment is particularly difficult, but if successful, can be reliably applied in a wide variety of fields including but not limited to
  - Self-Driving Cars
  - Environmental Survey drones (terrestrial, marine, and aerial)
  - Satellite Communications Arrays
  - Internet Certificate Authority verification
  - Distributed Computing

Conclusions

- In Progress

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