Behavior Recognition of an AUV Using a Forward-Looking Sonar

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Multi-robot teams, when compared to single agents, are more economical, more robust to failure, and more efficient. Cooperation strategies among a team falls within two main paradigms: centralized or decentralized. Centralized strategies require one agent to be the coordinator for the team. Though centralized strategies can deliver an optimal solution, they are prone to complete failure if the coordinator fails. Decentralized strategies are less prone to failure as teammates organize themselves in a distributed fashion. An example of this is the use of auctioneering methods as in Sariel et al. [5]. Cooperation among teammates is facilitated by good communication. However, as communication availability decreases, as in the underwater domain, even decentralized solutions suffer in efficiency [5]. Sotzing et al. [6] showed efficiency improvement for a multi autonomous underwater vehicle (AUV) team in a poor communication environment by incorporating predictions of teammate behavior and future task selection based on last known communicated information. This architecture allows an individual AUV to make task selection decisions based on communicated or predicted teammate behavior or task selection. Thus, a multi-robot team can still function efficiently through low communication by incorporating predictions of their teammates position and task selection but still require some communication to verify or correct predictions.

The ultimate goal of this work is to design a system capable of operating with as little explicit communication as possible. The desired system will use prediction of a teammate's behavior or task selection but include verification of this prediction when necessary. Although it has been suggested [1], to this author's knowledge no prior multi-AUV cooperative robotic architecture has employed physical verification of a teammate's predicted behavior or task in order to determine its own next task. In the absence of explicit communication, an agents internal state is determined by perceiving the agent's actions, implementing what has been called behavior recognition. This envisioned system will use behavior recognition as its method of prediction verification. It is postulated that prediction along with verification of teammates will improve team efficiency in poor communication environments such as in an underwater environment since even a properly functioning auv may not be able to communicate through devices such as acoustic modems. This preliminary work investigates the feasibility of an AUV performing behavior recognition of another AUV through a forward-looking sonar.

Behavior recognition has been deployed using probabilistic graphical models with input from an overhead sensor or from post-mission analysis. Han and Veloso [4] used Hidden Markov Models (HMM) to determine the behaviors of robots playing soccer with a centralized overhead camera. The vision system delivered location and velocity information of a robot and a soccer ball to the HMMs as these features were relevant to behaviors such as go-to-ball and move-behind-ball. Feldman and Balch [3] used similar techniques to recognize the behavior of honey bees. In this work, bee motions were first labeled (such as waggle) and then fed to HMMs. Vail et al. [7] used Conditional Random Fields (CRF), with improved accuracy, instead of HMMs to determine the behaviors of hide and seek playing robots. More relevant to this research, Baxter et al. [1] performed behavior recognition using HMMs on post-mission analysis of self-localization. At the end of an AUVs mission, it would deliver its GPS coordinates obtained through the use of underwater transponders. Behaviors were then determined using cardinally oriented motions such as Track West and Right U-Turn East. The use of a cardinally oriented frame instead of specific GPS coordinates was an attempt to make these methods agnostic to absolute position.

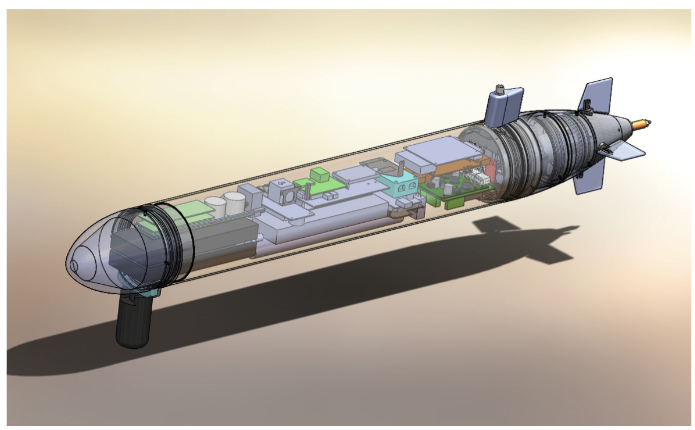

Fig. 1. The Yellowfin AUV.

The AUV used in these experiments is the Yellowfin [8], which is visualized in figure one. The Yellowfin AUV uses a BlueView forward-looking sonar along with a compass and an IMU for perception. Communication is performed through a WHOI acoustic micro-modem. The Yellowfin uses the Back-seat/Front-seat software architecture paradigm. The Front-seat is performed through an XMOS real-time micro-controller which interfaces with the sensors and actuators. The Back-seat is performed through a PICO single-board-computer (SBC) with an Intel Atom processor. The PICO SBC runs MOOS-IvP [2] which is responsible for Yellowfins AUV autonomy. The MOOS portion of MOOS-IvP is a communication middleware allowing for nodes to communicate through a centralized MOOS database. The IvP portion of MOOS-IvP are nodes designed for various autonomy processes specific to AUVs such as maintain depth and acoustic communication. Behavior recognition is implemented as a MOOS-IvP node which subscribes to the sonar tracking data and publishes perceived teammate behavior.

In this preliminary work, a BlueView forward-looking sonar is held stationary while a Yellowfin vehicle performs behaviors. In order to keep the perception of the Yellowfin's actions location-independent, vehicle actions will be encoded relative to each other. From one time step to the next, a vehicle can move forward, turn left, or turn right. Each action will be encoded numerically one through 5 with a three being assigned when the Yellowfin vehicle moves straight. A sharp left turn will be encoded with a one while a sharp right turn will be encoded with a five. A two or a four designates a slight left or right turn, respectively. This encoding is then used to train an HMM for each of three possible behaviors: search pattern, loiter, or circle target. Once these HMMs are trained, they are then used to detect the behaviors being displayed by the Yellowfin as seen through a BlueView forward-looking sonar.

These preliminary results demonstrate the viability of performing behavior recognition of an AUV through a forward-looking sonar. As the Yellowfin AUV itself uses a BlueView forward-looking sonar, we have demonstrated that it is possible for one Yellowfin AUV to recognize the behavior of another Yellowfin AUV in situ. The next challenge is performing behavior recognition while both AUVs are in motion. Real-time behavior recognition is a piece of a desired multi-AUV cooperation framework that allows for continued and optimal efficiency in a distributed system in low- to no-communication environments utilizing teammate prediction and verification.

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