Fault Detection, Diagnosis, and Mitigation for Long-Duration AUV Missions with Minimal Human Intervention

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LONG-TERM GOALS

Our goal is to give an Autonomous Underwater Vehicle the ability to autonomously detect and mitigate problems while simultaneously simplifying mission configuration. We will do so by creating a set of tools for abstracting vehicle performance, and using that framework with an onboard simulator to detect, diagnose, and mitigate failures.

OBJECTIVES

For autonomous systems to be successful for long deployments, they must be reliable in the face of subsystem failures and environmental challenges. For example, should an AUV suffer the failure of one of its internal actuators, can that failure be detected and mitigated, or does the failure result in the loss of the remaining deployment or even the loss of the vehicle? If the vehicle runs into the seafloor and picks up mud, will it recognize that it is heavier? Reliability connects all aspects of a robotic system, from the individual components of the robot to interactions with the environment, to the software that manages the system to achieve its goals. Our objectives are:

- To reduce the need for operator intervention in the event of performance anomalies on long-duration AUV deployments,

- To allow the vehicle to detect and mitigate failures and incipient failures based on performance and dependency models.

- To enable operators with good vehicle understanding, but no software skills, to update vehicle and failure models to improve reliability.

- To simplify mission configuration and reduce the chance of operator error.

APPROACH

We are developing software and hardware for autonomous underwater vehicles (AUVs) to autonomously: 1) detect faults and failures, 2) identify the source, 3) identify actions to respond, and 4) choose the best response. The response should allow the mission to continue, or at least ensure the vehicle and data are recovered safely. We are developing a semantic framework which captures the

description of the system, subsystems, the environment, and dependencies. This description, encoded within the framework, will be a 'living document' that is created and updated via a variety of methods, including by operators. We will use this framework to develop anomaly detection strategies, to probabilistically determine the root cause of failures, and to propagate understanding of failure to mission options. Such activities will occur both under supervision, in simulation, and autonomously. The desired endpoint is a framework that is scalable and organic in nature, handles a wide variety of failures - including the unexpected gracefully, and is easily understandable to both the developer and the operator.
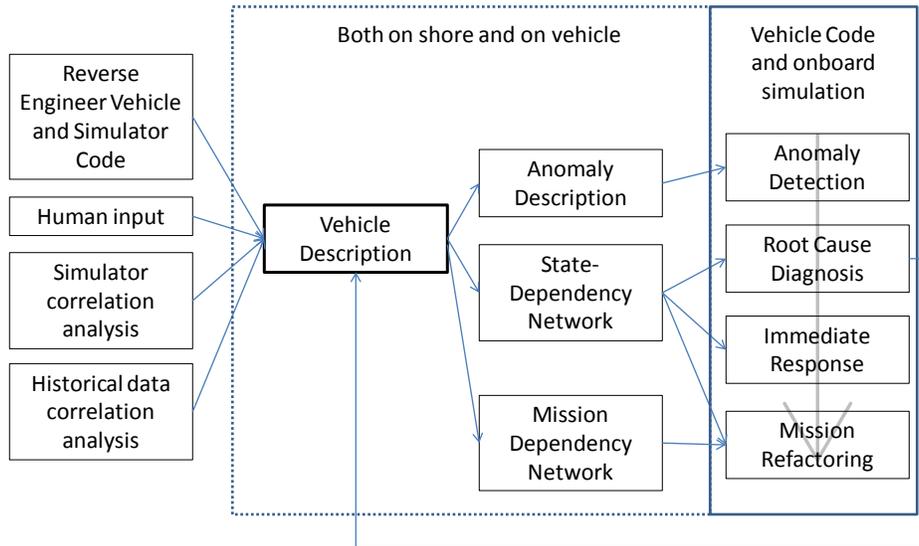

Figure 1: Framework for vehicle reliability uses a formalized vehicle description which is both intuitive to the operator and can be used to automate fault detection and recovery.

The base platforms for this effort are the Tethys LRAUVs (Figure 2). Tethys occupies the design space intermediate between gliders and the current generation of propeller-driven AUVs [Bellingham et al., 2010]. The vehicles are small, 30 cm (12 inches) in diameter and 2.3 meters long, and easy to handle. They are typically shore-launched and recovered, using a small boat (e.g., a Boston Whaler) to tow the vehicle between the harbor entrance and a boat launch ramp. Three vehicles have been built at MBARI and a three more are under construction. Deployments are unattended by ships, and range from a few days to over three weeks [Hobson et al., 2012]. The longest range mission to date was over 1800 km at a speed of 1 m/s. In that deployment from and to Moss Landing, CA, the vehicle operated as far as 500 km from shore independent of a ship. The vehicles interact with operators intermittently via an Iridium satellite link.

Figure 2: (left) Two Tethys-class long range AUVs. Tethys is in the foreground with the standard short nose configuration, and Daphne is in the background with a longer nose for increased payload volume. (right) Daphne with a turbulence sensor package, prior to deployment.

The extensive at-sea operations of the Tethys LRAUVs provides approximately 7000 hrs of vehicle logs. Although no vehicles have been lost, numerous failures have occurred during vehicle operations. These provide both a valuable source of insight into the

WORK COMPLETED

Work has been initiated on:

- Cataloging and analyzing historical data for past failures in LRAUV deployments (see table below).

- Developing initial "operator centric" failure terminology

- Evaluating simulator-based anomaly detection, using historical failures

MBARI Team consists of:

- J. G. Bellingham – PI (moving to WHOI in the coming year)

- Ben Yar Ranan – Anomaly detection work and

- B. Kieft and J. Stanway – LRAUV Code Expertise

- Y. Zhang – Classifier design and signal processing.

The OSU Team consists of:

- M. Abbott – PI for OSU

- W. Dixon – Operator tools

	Vertical plane					
	Vertical Control	Elevator servo	Thruster servo	Mass servo	Buoyancy server	Keller/DVL /Depth
Remote Intervention Required	68	31	43	18	25	6
Vehicle Triggered Emergency Recovery	5	0	0	0	0	0
Required Physical Intervention	1	0	0	2	0	0

RESULTS

Cataloging of past failures is providing both a training set for falure detection work, and insights into the nature and frequency of failures. Here we are greatly aided by prior investments to detect, catalog, record, and mitigate failures [Kieft et. al, 2011]. Particular attention has been given to faiures that effected the vehicle's ability to manuever in the vertical plane, since these can be catastrophic. In approximately 7000 hours of AUV operations, 96% of vertical-plane vehicle mission aborts have been problems that could be solved remotely via a satellite link. Of the remaining failures, the majority were deamed serious enough by the software that extreme emergency measures were taken (i.e. the drop weight was fired). These were managable remotely, but effected vehicle performance. The smallest portion of the failures required physical human intervention (i.e. the vehicle had to be rescued).

A simulator for vertical plane behavior of the vehicle has been implemented, using an AUV model developed by Prestero [2001] as a starting point. The simulator's parameters are can be tuned to match actual vehicle performance quite well (see figure 3).
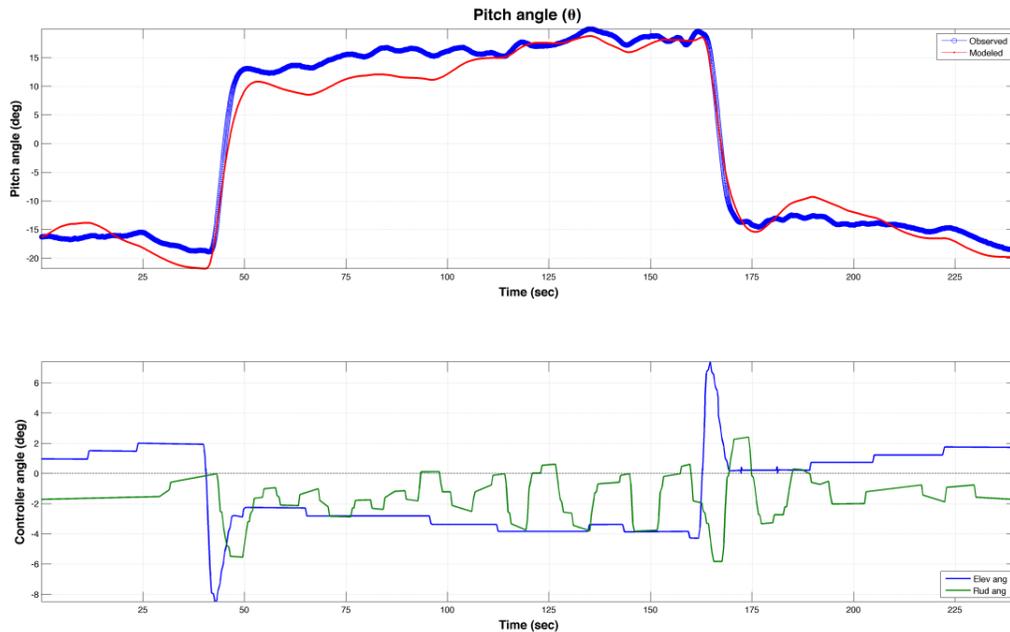

Figure 3: Comparison of simulator and actual vehicle performance. Top plot shows vehicle pitch response to control input given in bottom graph.

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The simulator provides a tool for evaluation of vehicle flight performance. Figure 4 shows a time series of vehicle depth during a run in which the internal mass shift in the vehicle failed, causing the vehicle trim to shift to a nose-down attitude. If this failure information had been available to the vehicle, bottom impact could have prevented by the simple expedant of shutting off the thruster and ballasting the vehicle positive. The comparison also shows a flight anomaly earlier in the run, possible caused by an impact with something in the water column.

IMPACT/APPLICATIONS

Robotic systems offer a potential avenue for the US Navy to improve capability while at the same time decreasing costs. However, the undersea domain does not have the high-bandwidth communications links that the air and ground domains use to enable human operators to directly control unmanned vehicles. What communications do exist either depend on the vehicle coming to the surface, or are low bandwidth and short range. Consequently, undersea vehicles must be capable of operating free of human supervision for extended periods to carry out useful naval missions. In practice, most autonomous systems are designed to 'call for help' from human operator for all but the simplest failures. This project directly addresses the need to minimize human 'hand-holding' by developing architectural solutions for autonomously detecting, diagnosing, and handling faults and failures.

RELATED PROJECTS

This project draws on work carried out in Award Number: N00014-10-1-0424, "Compact ocean models enable onboard AUV autonomy and decentralized adaptive sampling."
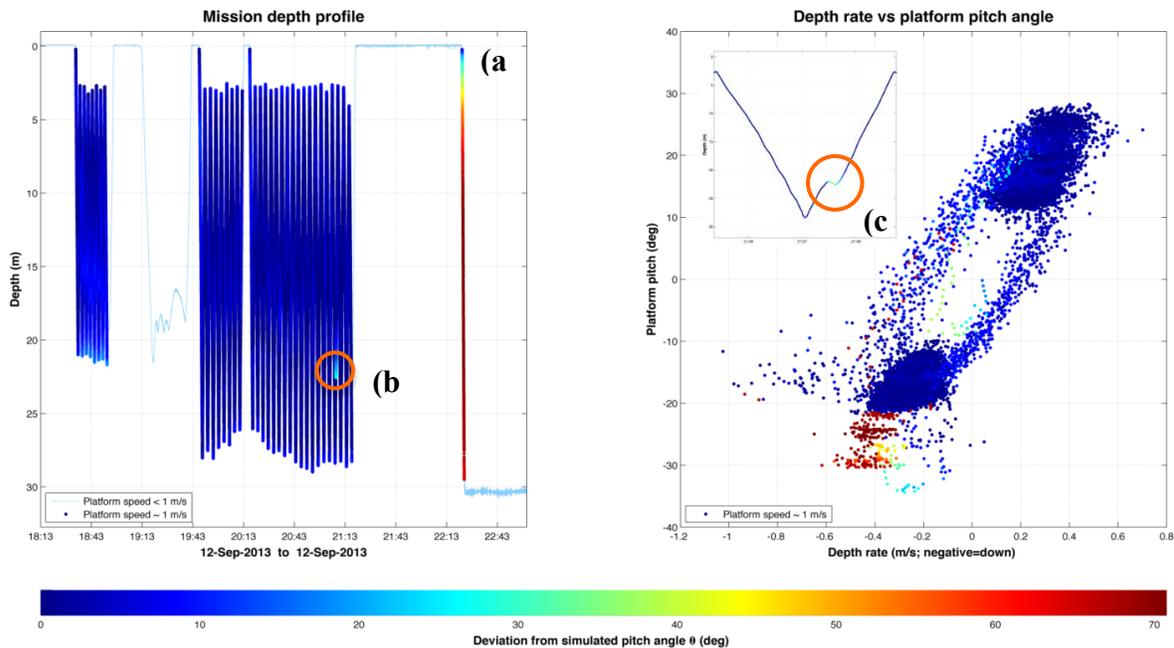

Figure 4: (left) Time series of vehicle depth, with color bar indicated degree of pitch discrepancy between AUV performance and simulator performance. Event (b) indicates a brief excursion of pitch from predicted performance. Event (a) shows where the vehicle is no longer controllable in pitch, due to a failure of the mass shifter, ending with the vehicle impacting the bottom. (right) Pitch versus depth rate, with the same color bar. The extreme low pitch correlates with the pitch performance anomaly.

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