Adaptive Calibration of an Autonomous Underwater Vehicle Navigation System

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Abstract **- There continues to exist the problem of long-term accurate position estimation for autonomous underwater vehicles (AUVs). In current operations, the AUVs positional fix is initially obtained on the surface from a global positioning system (GPS) receiver. The AUV then submerges to perform the desired mission. While submerged, location / navigation is performed using, at a minimum, an inertial navigation system (INS). Depending on the sophistication of the AUV, Doppler velocity sonar (DVS) might be combined with a multi-state Kalman filter (KF) to perform position estimation. The estimates from the INS and the DVS / Kalman filter estimator are combined to provide a robust estimate of location. Because the KF is model based, there is likelihood that over time the divergence of the KF may increase since the true motion of the AUV does not match the modeled motion. At that point the AUV must surface to obtain another set of absolute position coordinates from the GPS before being able to continue its mission. Depending on the duration of the mission, this process may need to be repeated several times, which unnecessarily uses battery / power resources. By combining a database which contains sonargrammetric, terrain matching, and image registration information, with the standard navigation instrument suite, the accuracy of positional estimates could be maintained over a longer duration. This would allow the AUV to remain submerged for longer periods of time, thus minimizing the drain on the limited power resources.**

I. BACKGROUND

Autonomous underwater vehicles (AUVs) require some type of positioning system in order to carry out a given mission. It is of utmost importance that the vehicle accurately maintains both absolute and relative positional information for itself and of artifacts in its surroundings. Absolute position refers to a globally unique location, an object's latitude, longitude, and depth. These attributes define where the vehicle or object is in the world. Relative position refers to the location of the vehicle with respect to its surroundings. This information may include range and bearing to nearby objects, as well as texture and contour information of the ocean bottom. All together, positioning information is used to aid in the development of the operational scene.

Advanced navigation systems use a combination of global positioning system (GPS) and ring laser gyro to keep track of position with a very high degree of accuracy. Unfortunately, this accuracy is directly proportional to cost, making such positioning systems prohibitive for many of today's AUVs. Thus, most AUVs employ lower cost, less accurate gyro systems with the understanding that re-calibration will periodically be required over the duration of a submerged mission. These re-calibration operations result in a reduction in mission efficiency and efficacy. As depicted in Fig. 1, this "do work, surface to recalibrate, do work" mission progression can be changed into a continuous "do work" paradigm if the AUV can accurately keep track of its absolute position for a longer period of time.

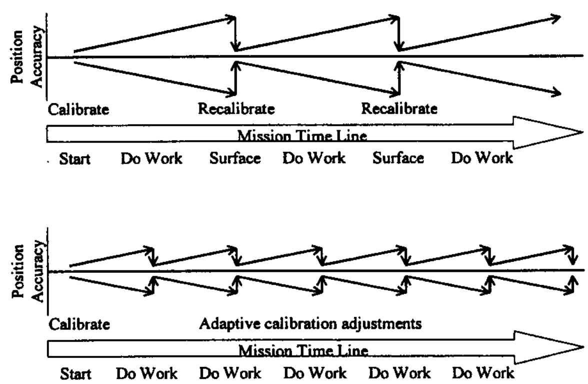

Fig. 1. Mission progression as a function of drift in vehicle absolute position accuracy. The "do work, surface to recalibrate, do work" mission progression (top) can be transformed into "do work, do work, do work" (bottom) when the positional error is kept below an acceptable level.

In addition, by extracting and exploiting attributes surrounding the AUV in its operational environment, it should be possible to adaptively calibrate the AUV navigation system on the fly, thus restoring mission efficiency and efficacy. By minimizing or even alleviating the need to surface for absolute positioning re-calibration, the vehicle can make better use of its limited energy resources. Furthermore, the vehicle can now be more effective by completing its mission in a shorter amount of time, extending the duration of its mission, or reducing the risk of being detected during covert operations due to having to re-surface.

II. ALGORITHM / SYSTEM DESCRIPTION / SYSTEM DEVELOPMENT

The general system diagram is shown in Fig. 2. Overall, the system is comprised of four major subsystems: Positioning System, Sensor Suite, Adaptive Calibration, and Historical Database. The Positioning System is the standard INS/KF configuration for maintaining estimates of the vehicle's absolute position, heading, and speed. The Adaptive Calibration System correlates sensor measurements provided by the onboard Sensor Suite with a Historical Database of preloaded information about the vehicle's operating environment. Given sufficient correlation the adaptive calibration system generates an appropriate calibration feedback to the AUV navigation system. This feedback is the difference between where the navigation subsystem estimates the AUV to be, and where the calibration subsystem estimates the AUV to be. Additional information about the environment, such as the gradient or topology of the ocean bottom, may also be used to aid in this positioning alignment process.

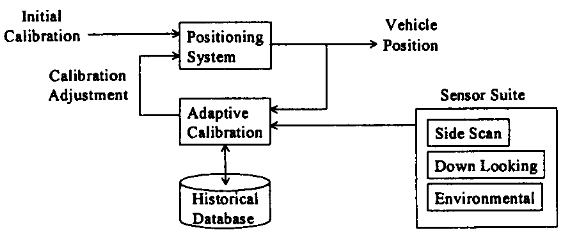

Fig. 2. System diagram; comprised of four major subsystems: positioning system, sensor suite, adaptive calibration, and historical database.

A. Process Initialization

At the beginning of the mission several initialization tasks occur, including determination of the vehicle's present location from the GPS receiver, and downloading of the object and map database. Once in motion, and before submersion, the AUV takes a second GPS reading. These two readings can be combined to provide heading and Cartesian velocity information. These values are then used to initialize both the inertial navigation system (INS) and the Kalman filter. Inputs to the Kalman filter include the Doppler velocity sonar (DVS). During operation, the estimated position and velocity states from the Kalman filter are compared with those of the INS and, when appropriate, the object database as well.

B. Sensor Suite

Present AUV 'standard' navigational equipment includes a combination of sensors [1] designed to monitor the vehicle's health, motion, and environment. In addition to a 3-axis rate gyro, GPS receiver, and vertical gyro, the sensor suite typically incorporates color or infrared cameras along with some form of side scanning and profiling sonar for detecting, classifying, and localizing nearby objects. When in a downward looking configuration, the sonar can also be used to measure topological characteristics of the ocean bottom. Other commonly used sensors include a compass for measuring vehicle heading, a bathometer or fathometer for measuring water depth, and a thermometer for measuring water temperature. Additional sensors for measuring water salinity, turbidity, and bioluminescence are also often included. Together, the sensor suite facilitates the higher level functions of object recognition and terrain following.

C. Database Management and Object Correlation

With no source of absolute position measurements available once submerged, underwater navigation is confined primarily to some form of internal navigation system (INS) and relative positioning sensors, i.e., sonar. In this implementation Terrain Contour Matching (TERCOM), Digital Scene Mapping Area Correlation (DSMAC), and object pattern data with known absolute coordinates are stored in an extendable adaptive object/image database. TERCOM employs elevation maps from which general location information can be extracted. In air-based implementations DSMAC is used primarily for terminal guidance. In the undersea scenario it would be of wider scope, being used to narrow the applicable region when searching for known waypoints.

Unfortunately, large databases of high-quality terrain and mapping information similar to that available from the National Imagery and Mapping Agency (NIMA) does not exist for the undersea environment. Therefore, for the undersea scenario, known scene information [2, 3] would be downloaded to the AUV and stored in the relational database.

The scene information stored in the database could consist of any combination of terrain and elevation information, natural and man-made formations with acousto-optic as well as geometric descriptions (i.e., the object description could contain sonar signature information as well as edge / boundary [4-Fig. 10.10, 5] information at various perspective angles). The database would also contain absolute GPS coordinates for each object. The AUV would make periodic correlations between its field of view and information contained in the database. However, as battery power decreased or KF error increased, the time between sonar scan and database correlations would increase. If no matching fixed-point pattern were available, and the location drift reached an unacceptable level, the AUV would make the decision to surface in order to calibrate its position. Similar to its normal scan / correlation operations, the AUV would survey the environment for objects that were not in the database. This data could then be added to the database along with the object's geometric / sonar return signature information and positional information. After surfacing and obtaining absolute position coordinates from the GPS receiver, the coordinates of the newly added objects would be validated. The AUV would then submerge and continue the mission. Similarly, if an object in the AUV's surroundings could not be located, it could be flagged as missing and upon confirmation, removed from the database. It is intended that the database be a dynamic entity. In addition to extracting information used for positional calibrations during the mission (i.e., terrain matching), it also functions as the repository for terrain completion and terrain mapping missions.

D. *Adaptive Calibration*

The calibration adjustments are used to align or re-initialize the vehicle's positioning system with respect to known locations of identified stationary objects in the vehicle's environment. Location correction terms are computed as the difference between the vehicle's absolute position based on INS estimates, and the vehicle's absolute position based on the known location of an identified object in the AUV's environment. Recall that the sensors detect and identify a stationary object, and that object's absolute location is extracted from the database. Since the vehicle's sensors have also measured the relative range and bearing to the object, the vehicle's position may be expressed as a relative position from the object's perspective. Given the absolute position of the object, it is then possible to determine (or triangulate) the vehicle's absolute position, and therefore the positional error.

CONCLUSION

The addition of an adaptive object database in the navigation loop provides another means of extending the submerged portion of an AUV mission by continuously monitoring the environment and providing positional feedback by means of adaptive calibration. While submerged, periodic encounters with known objects would allow near-GPS precision updates to both the INS and the Kalman filter. Encounters with unknown objects are an opportunity to update the object database.

By fusing and registering images obtained from different sensors, the likelihood of locating map / terrain / database objects is increased in the non-homogeneous environment. With the rapid advancement in the state-of-the-art of underwater imaging sensor technology, additional equipment, such as blue-green lasers and infrared cameras, may prove to be valuable sensor suite augmentations in order to enhance the AUV positional accuracy.

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