Automated Solutions to the Underwater Port and Harbour Security Problem

Dr Scott Reed

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Context

The security of our Port and Harbour areas is coming under increased scrutiny due to growing concerns of a possible terrorist attack. Environmental pressures to control vessel discharges, along with counter drug concerns regarding contraband smuggling further highlight the need for a robust-repeatable solution to monitor and inspect these regions. These surveys must provide detailed coverage information, allow possible mine threats to be localised and should allow comparisons with historic data sets. The proposed solution should be man-portable, be simple to use, allow frequent inspections and require little training.

Hull and Harbour infrastructure inspections are currently not performed regularly as they require careful planning, they are time consuming and they require large amounts of monetary resources. Manual Diver-centric operations offer an unacceptable level of cost, risk and require substantial training. Other options include the use of Remotely Operated Vehicles (ROV's), which may be deployed to inspect the constrained harbour regions such as the pier pilings, ship hulls and harbour walls. These vehicles can be deployed quickly, mounted with increasingly sophisticated sensor payloads and operated continuously in adverse conditions. However, controlling the vehicle while also assessing the live sensor data and managing the ROV tether is a difficult task. Manual, joystick controlled operations lack stability and cannot provide accurate navigation information. This uncertainty makes coverage estimation and object re-localization very difficult.

This paper considers the problem of Port and Harbour security and discusses how autonomy-based systems can be used to aid to provide a robust-repeatable solution. Ports and Harbours may be split into distinct open and constrained regions. Within the open water areas, there is a clear need to remove divers from the task of detecting possible targets. This task is exceedingly dangerous, time consuming and it is very difficult to assure 100% coverage. Within the constrained areas, diver and manual ROV operations provide poor stability and coverage and should be replaced by solutions which are safer, cheaper and faster.

SeeByte solutions provide autonomy inspection tools for both the open and constrained areas of the harbour. These robust-repeatable solutions provide a capability to conduct frequent inspection surveys and provide the operator with improved situational awareness. These survey capabilities must be used in conjunction with active, real-time threat detection systems for diver detection to provide a complete Port and Harbour security solution.

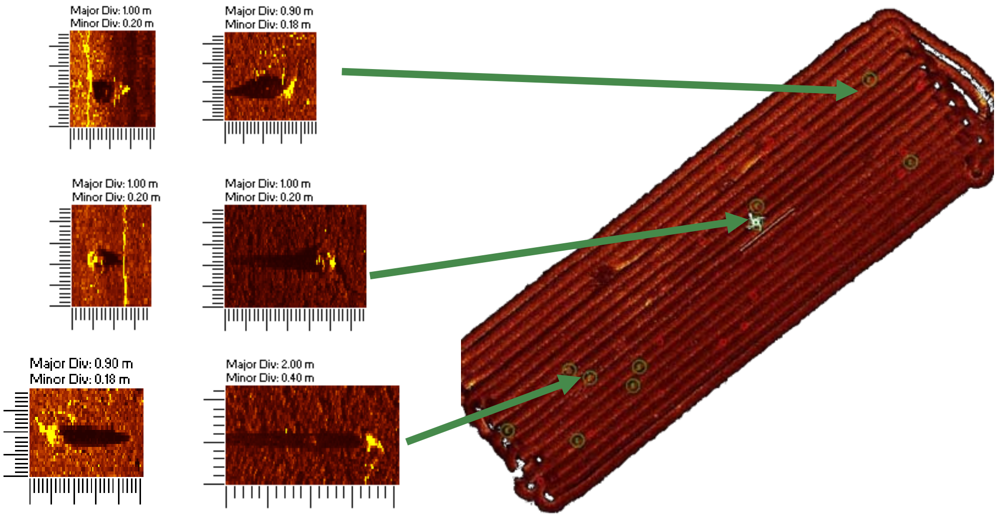
This paper outlines SeeByte's available autonomy solutions for inspections in both open water and constrained environments.

Open Water Inspections

When inspecting the open water regions of the harbour, Autonomous Underwater Vehicles (AUV's) may be used to search, classify and identify mine-like threats. These vehicles are routinely used in Mine-Counter-Measures operations where they are programmed to conduct lawnmower trajectories, providing high resolution sensor data while assuring a 100% coverage rate. Navigation sensors now provide positioning capabilities which enable an object to be accurately localised and re-acquired. Sonar technologies such as Synthetic Aperture Sonar (SAS) also provide large range, high quality data which provide a high coverage rate and sonar imagery that provides the resolution required to detect, classify and identify mine threats. These sonars are now being mounted on AUV platforms as part of routine operations. However, in current operations, these AUV's are still used primarily as simple data collection devices. The AUV mission plan is pre-programmed while the sensor data is analyzed post-mission by an operator.

It is now common for Navies to use a variety of vehicle assets, making it impractical and unwieldy to have separate software packages for each vehicle and sensor type. SeeByte address this need with SeeTrack Professional, a modular suite of software components which provides multi-vehicle mission planning, monitoring and post processing capabilities for rapid on-site analysis and data fusion of the sensor data. It uses a modular open architecture that provides a single integrated picture for all assets being employed within the Harbour region. It has been used successfully to coordinate multiple AUV operations.

SeeTrack Professional includes a Change Detection component which fuses and compares data from multiple missions to highlight possible new threats. This capability is a critical aspect of Port and Harbour Inspections where the region is well known, controlled and needs to be frequently inspected. The ability to conduct Change Detection operations is dependent on being able to accurately register data from multiple missions. Other approaches attempt Change Detection at the Data Level by running the same vehicle and sonar setup through exactly the same mission plan. These approaches are susceptible to modifications in the environment and require a level of navigational accuracy which cannot be guaranteed. They also require that the same system and group of assets is used each time.



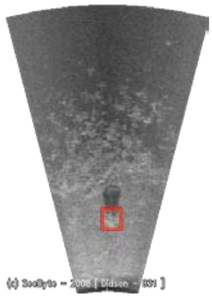
SeeTrack Professional conducts Change Detection at the meta-data level; fusing and comparing detecting geo-referenced contacts from the different missions. Any sensor or vehicle which is compatible with SeeTrack Professional can therefore contribute to the Change Detection process. Operator or Automated Target Recognition (ATR) feedback may be used in the process. Fusing data in this manner removes the need for the vehicles to swim exactly the same mission. The vehicles also do not need to be equipped with the same sensor configuration. The operator therefore has greater flexibility; they may use a wide range of assets and can plan missions based on the particular scenario and available assets. Vehicles and sensors may be replaced and interchanged while different mission plans may be used. All available data can be read into SeeTrack Professional, geo-referenced and recent changes highlighted. The software provides the user with a flexible, adaptive approach to Port and Harbour security.

Where is the technology heading?

Future capabilities will go much further. The most advanced COTS Change Detection software just now considers positional navigational information only to highlight possible contacts. Autonomous Change Detection capabilities will require the ability to robustly classify and identify targets across multiple sensors. Sensors and Target Recognition algorithms will advance so that they may adapt to the specific scenario and provide identification information on each object. In cluttered environments where there can be multiple objects in close proximity, the use of navigational information in isolation will not be sufficient to flag new threats. The ability to identify objects into distinct features such as rocks, tyres and mines will be required for the data association process. Some AUV-mountable sensors are now capable of providing the resolution to allow ATR algorithms to provide this level of granularity. Others cannot and provide only coarse resolution details. Robust Change Detection systems will accept input from different sensors and ATR models at the level of granularity they can provide, fusing and comparing the data at the appropriate level of richness to extract the most information.

Robust ATR models which are capable of identifying specific objects when the sensor resolution justifies it will be required. SeeByte are world experts in ATR development and have demonstrated that supervised learning techniques may be used to consistently identify known objects with a low false alarm-rate. Within the Port and Harbour area, the same type of objects and debris are seen frequently; these may be “learnt” by the ATR model and consistently detected and discarded thereafter. These same features may also be used as ‘navigation beacons’ to allow the AUV to re-localise itself in-mission. ATR models will need to be adaptable and provide the capability to learn new targets once relevant data becomes available. Future autonomous Change Detection models will use supervised, in-situ ATR algorithms which may be adapted or enhanced by the operator. These models will provide high-level object ID information into the Change Detection model, allowing object discrimination and threat detection even within the most cluttered environments.

Inspection routines within the open Port and Harbour regions will become more automated, utilizing multi-vehicle operations. The operator will no longer need to specify vehicle mission through a series of waypoints but will specify high level goals; for example, conduct a Change Detection mission and report back. This will remove the need for the operator to plan the mission at the waypoint level, reducing operator error and speeding up planning times. It will be the role of the Autonomy modules to determine how best to fulfil the goal of the mission based on the vehicle assets available and their suitability for each task. Multiple assets may be required based on their operational suitability or sensor configuration. Vehicles may request assistance from each other. One possible scenario is that a vehicle detects a possible new target but lacks the sensor resolution capabilities to properly classify the target. It would therefore request the assistance of another vehicle equipped with suitable sensors to resolve the issue.



For this multi-vehicle co-operative behaviour to be possible, the vehicles will need to share a World Model, which will provide an up-to-date representation of the vehicle’s world. Each of the vehicles will be able to update the model which will hold information on relevant features within the Port and Harbour area. This model will be continually updated each time a vehicle operation is conducted and the results transmitted to the other vehicles. The vehicles will share a common World Model and view of their environment and use this to collaboratively work together and detect possible threats.

Finally, as operations become more autonomy based, specific care will need to be taken to reduce the knowledge gap between the vehicles and the operator. If the vehicles are able to build their own mission plan, make decisions and modify their behaviour in-mission, it is vital that the operator is able to trust the system. This barrier will be overcome using Natural Language and advanced visualization systems which will allow the operator to interact, check and query the autonomy system.

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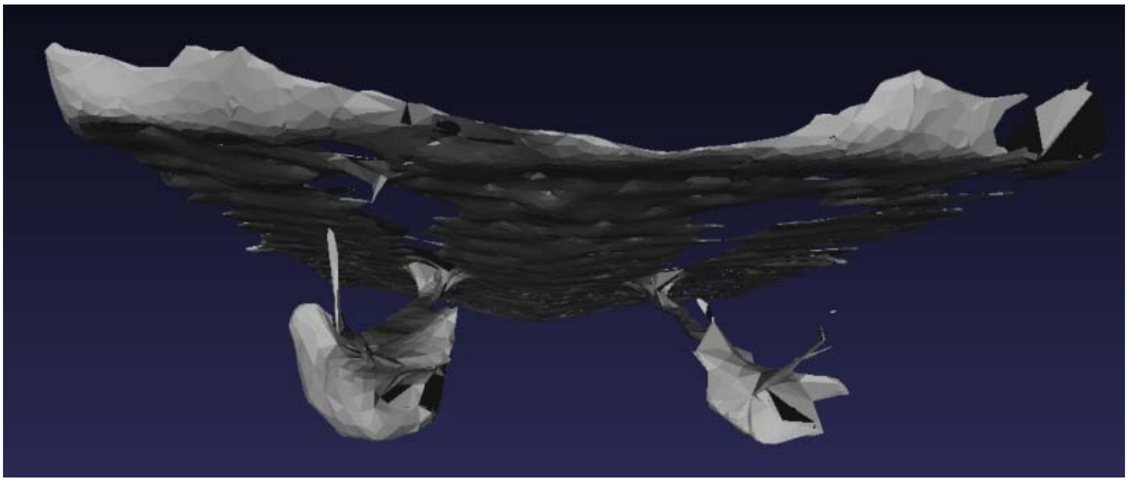
Constrained Environment Inspections

When moving to the constrained areas of the port such as around the harbour walls and near the ship hulls, it is necessary to provide both a persistent surveillance capability to monitor soft targets and entry points as well as providing an inspection capability to regularly inspect the harbour.

Diver Intruder Detection is an area of key interest and is being looked at using high resolution Forward Looking Sonars. SeeByte have developed ATR algorithms which are able to robustly detect divers and track them over time. These algorithms have been made compatible with a large number of sonars and a solution can be tailored to meet the needs of the operator or specific hardware system.

Inspection operations within the constrained harbour areas are currently conducted by divers. This is a skilled and highly dangerous task where assuring 100% coverage is almost impossible. Re-acquiring possible threats is also very difficult due to localization problems. Autonomy solutions may be provided either using a hover-capable AUV or an ROV. There are now several COTS ROV systems which provide affordable, man-portable solutions for carrying out inspections within constrained environments. These provide a stable platform on which high resolution sensors such as forward looking sonar (FLS) and optical video cameras may be mounted. Many underwater operations that were once carried out by divers can now be carried out more quickly, more efficiently and in a more repeatable fashion using ROVs equipped with smart control and sensor processing software.



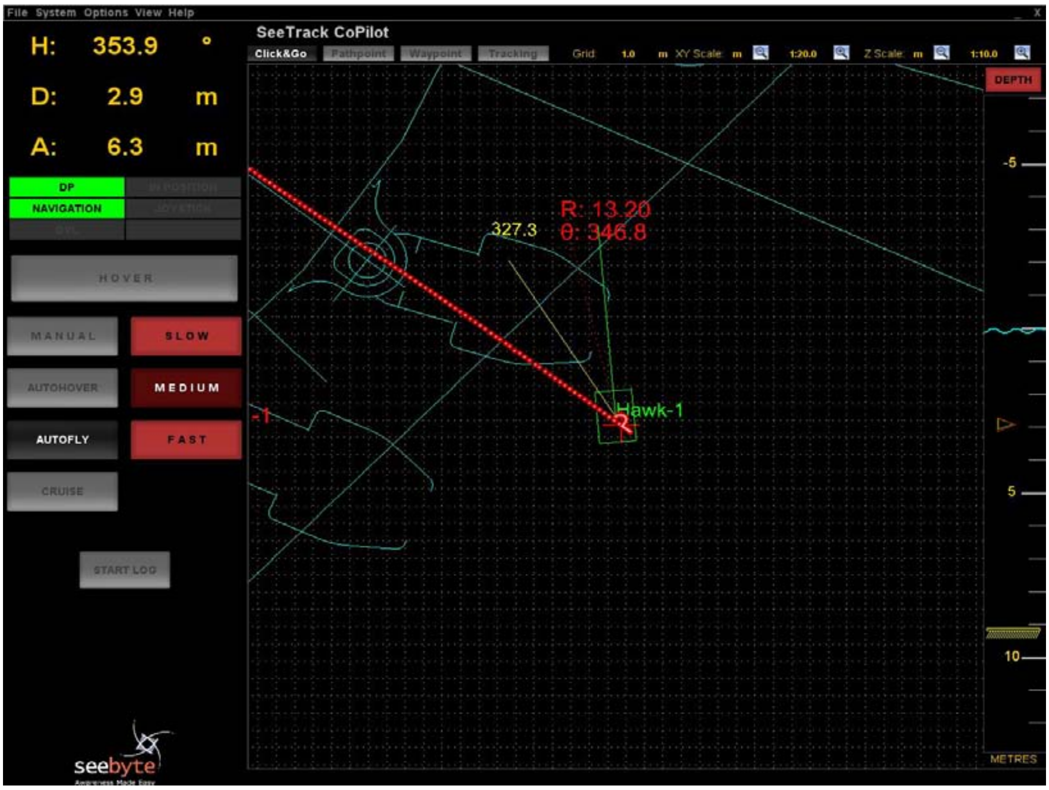
The manual control of an ROV using a joystick is a challenging and highly skilled task. Controlling the ROV in a constrained environment while also assessing the live sensor data is a very skilled and time-consuming task. SeeByte's SeeTrack Co-pilot provides a vehicle independent, dynamic inspection and sensor-servo capability. This allows the operator to run pre-planned mission templates, or directly control the vehicle via an intuitive interface or via a joystick. This low-level control provides vehicle stability and ensures external factors such as sea currents do not impact the ROV performance. This capability has been demonstrated on multiple vehicles in severe offshore conditions and provides vehicle stability and control capabilities in constrained environments.

Where is the technology heading?

The future success of Diver Intruder Detection models will be dependent on their false alarm rate. It is unacceptable for a persistent surveillance system to continually raise an alarm due to false positives such as large fish or environmentally induced noise in the sensors. Algorithms must be developed which can be demonstrated to be robust-repeatable and provide very low Probability of False Alarm (PFA) values. In parallel, affordable large range, high resolution FLS are required which will allow divers to be detected at distances which provide the operators with a reasonable response time to deal with the threat.

Future ROV's will become smarter and will come equipped with Autonomy capabilities to either aid or replace the operator within certain tasks. The operator will monitor operations from an intuitive console. They will be able to request that the system autonomously inspects a specific hull or harbour region. Manual control of the vehicle will be possible when needed via a joystick of touch screen interface. On-board sensor data will be fed to the interface, providing the operator with an immediate picture of the environment.

Sensors on board the ROV will be used to actively lock-onto, detect and provide active feedback to the vehicle control modules. High level control modules can use this information to autonomously navigate the vehicle. SeeByte are world-experts in this field, and have demonstrated that an underwater vehicle may autonomously inspect subsea, ship and harbour features such as risers, ship propeller shafts and harbour walls. The sensors act as the vehicles eyes, providing real-time feedback and allowing the vehicle to navigate around unknown, complex structures. Smart-ROV solutions will allow the operator to select automated inspection tasks from a library, after which they may focus on their principle task of assessing the sensor data for threats while the vehicle conducts the survey.

\ 

Automated operator tools will be critical for successful operator-in-the-loop smart ROV operations. Typically, an operator assesses sensor data image by image. This provides a snapshot "window" of what the vehicle is seeing but does not provide any global context to aid the operator. Relating the data to the actual scene is very difficult. Real-time Mosaicing and 3D Re-construction capabilities will provide this information within the big picture; possible threats will be seen relative to well known features, providing the operator with a full situational awareness of the area being surveyed, gaps in the coverage and information on how re-acquire and neutralize the threat.

Automatic Target Recognition (ATR) models will process the data in real-time alongside the operator, cueing them to possible threats. The ATR modules will be able to take control of the vehicle, interrupting the pre-programmed mission to hover in front of the target until the operator has verified the threat or dismissed it. SeeByte have demonstrated all these capabilities within various programs of work and will seek to develop them further to meet future operator needs.

Future capabilities in this field will move more in the direction of Full Autonomy. The operator will provide the end-goal of the mission, which high level decision making software will break down into manageable tasks. Lower level controls will receive these task instructions and implement them. Provided with the goal of the mission, the vehicle will use its on-board world model to determine how best to transit to the relevant survey area within the harbour and execute its mission tasks.

Conclusion

This paper has given an insight into the state of the technology that can be used in Port and Harbour Security operations. The paper has concentrated on the solutions required to tackle the threat from underwater attacks and sabotage. It has provided an insight as to how technology developments will impact future operations and capabilities. The overarching thread is one of enhanced automation and simpler operations without compromising the final result. These autonomy capabilities must also be developed in parallel with improved human-vehicle interaction capabilities so that the operator retains full trust in the process. In SeeByte we are at the centre of the community providing autonomy solutions that will be indispensable to the future security requirements of our ports and harbours.