

The Automated Change Detection and Classification – Real-time (ACDC-RT) System

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Abstract

In support of Military Mine Warfare (MIW) clearance operations for safe vessel passage, analysts perform change detection by visually comparing historical high-resolution sidescan sonar imagery (SSI) with newly collected SSI in an attempt to identify newly placed objects. The objective of MIW change detection is to match objects detected in new SSI with historical objects stored in a database. Any newly detected objects not successfully matched are flagged for investigation. A requirement exists for a system to perform real-time change detection and classification.

This paper presents an Automated Change Detection and Classification (ACDC) System, developed by the Naval Research Laboratory (NRL) and the Naval Oceanographic Office (NAVOCEANO), which aids analysts in performing change detection in real-time (RT) by co-registering new and historical imagery and using automated change detection algorithms that suggest imagery changes. In this paper, ACDC-RT components are described and results given from a recent change detection experiment.

Introduction

This paper presents the development and testing of a prototype Automated Change Detection and Classification – Real-time (ACDC-RT) system developed by the Naval Research Laboratory (NRL) and the Naval Oceanographic Office (NAVOCEANO). ACDC-RT aids sidescan sonar analysts in locating proud objects on the seafloor over geographic areas where historical sidescan sonar imagery (SSI) exists. Using ACDC-RT, two analysts can perform “change detection” in real-time, i.e., as the SSI is being collected.

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NRL also has developed real-time (RT) change detection algorithms. Beginning in 2002 under 6.2 Exploratory Research funding, NRL modified existing ACDC components to perform RT change detection and apply the results to correct the position of autonomous underwater vehicles (AUVs). The premise was that an AUV would have an on-board database populated with features detected in historical SSI. The ACDC algorithms aboard the AUV would attempt to detect new features in RT, match individual features with features in the on-board database, and use this information to correct the AUV's position.

In support of this goal, NRL and NAVOCEANO demonstrated the ACDC-RT concept at a January 2006 Johns Hopkins University Applied Physics Laboratory (JHU/APL) change detection planning meeting using partially completed ACDC components with SSI collected during the 2005 JHU/APL Change Detection Experiment. NRL and NAVOCEANO further developed and demonstrated a proof-of-concept ACDC-RT system during the 2006 JHU/APL Change Detection Experiment. A description of the experiment and the results are given later in this paper.

Figure 1 shows the two main displays of the ACDC-RT system. The display on the left is a (time-based) waterfall display of SSI as it is being collected. The display on the right is a (geo-registered-based) waterfall display of historical SSI over the same area. ACDC-RT algorithms have detected a mine-like contact in the RT SSI (yellow box on the left display) and matched it with the same contact observed in the past (yellow box on the right display). Figure 2 is a close up view of the contact (present view on the left and historical view on the right). The position of the contact in the historical SSI compared to the position of the contact in the newly collected SSI is slightly different due to position error present between the two datasets. This is discussed later in this paper.

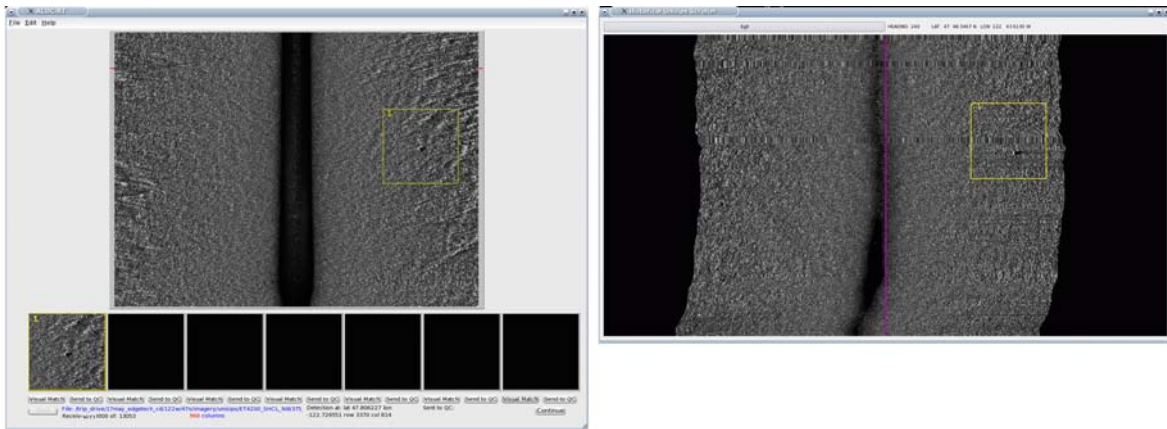


Figure 1 – View of the two main ACDC-RT co-registered displays. On the left is real-time SSI from a survey area, and on the right is historical SSI over the same area. The yellow boxes in both displays contain the same contact, automatically detection by the ACDC-RT software, observed in both surveys (new and historical).

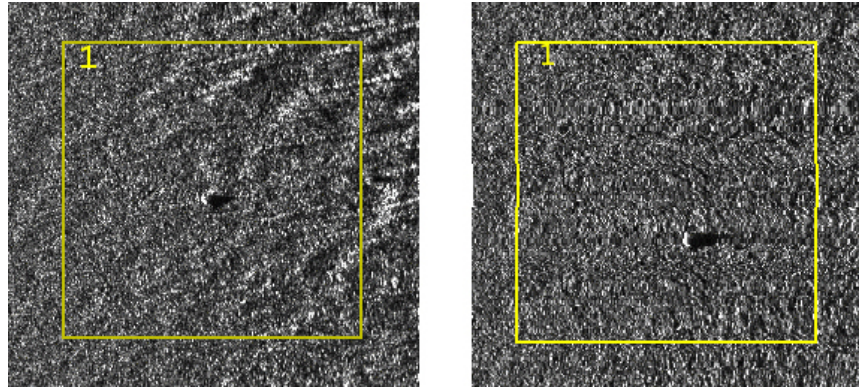


Figure 2 – Close up view of the same contact observed in the present (left) and the past (right). Note that contact in the historical SSI (right) is not in the center of the yellow box. This is due to position error between the historical and RT SSI.

Before ACDC-RT is discussed, an overview of sidescan sonar basics and change detection using SSI is given. Details of the 2006 JHU/APL Change Detection experiment are then briefly given along with results of the performance of ACDC-RT during the experiment.

Sidescan Overview

Dr. Harold Edgerton at the Massachusetts Institute of Technology (MIT) first developed sidescan sonar in the 1960's. The sidescan sonar system (SSS) transmits an acoustical beam on each side of a transducer, sometimes called the “fish.” The beams are sent in a wide angular pattern down to the bottom in swaths 50-500 meters wide, and the echoes are returned creating a narrow strip below and to the sides of the transducer track (Blondel and Murton, 1997).

The SSS are usually towed from a platform, such as a ship or helicopter, hull-mounted, or carried on AUVs. The fish is often equipped with a pressure or altimeter sensor that allows it to follow the bottom while maintaining a constant height above the seafloor or alternatively “fly” at a constant depth below the surface. Important measurements such as heading, pitch, and roll are recorded on-board AUV or, in the case of towed transducers, are often transmitted up the towing cable and recorded separately on the towing vessel (Fish and Carr, 1990).

Because the Global Positioning Systems (GPS) does not function underwater, the position of cable-towed transducers is calculated from the GPS location of the surface vessel by using a cable layback model or acoustic tracking system (Schwab et al., 1991; Kenny et al., 2001).

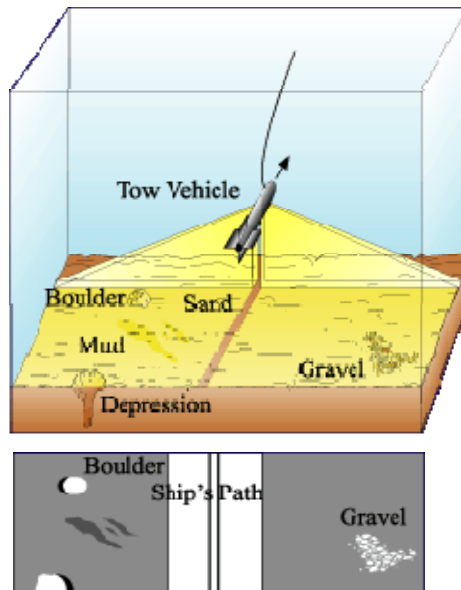


Figure 3. Depiction showing a sidescan sonar system (SSS) imaging over the sea bottom.

Figure 3 depicts a SSS being towed. The beams strike the seafloor and are reflected back to the fish. Processing and sampling the raw sidescan data forms scanlines that make up grayscale SSI (Figure 4). Directly below the fish, called nadir, the SSS is blind due to the spreading of the beams.

Objects close to or on the seafloor, such as mines, can be detected with SSI. These objects, or contacts, show up in the SSI as bright spots with adjacent shadows that face perpendicular away from nadir. Features of various shapes and sizes can be detected by the shadows (Collet et al., 1996), and the size of the shadow varies as a function of beam angle and feature dimensions (Fish and Carr, 1990). Figure 5 shows an example of a small image extracted from SSI called a snippet that contains a contact. NAVOCEANO maintains a Master Contact Database (MCDB) containing thousands of features detected from SSI worldwide since the early 1990's.

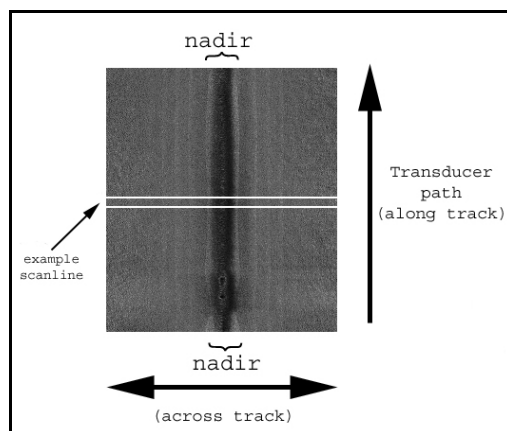


Figure 4. Sidescan Sonar Imagery (SSI).

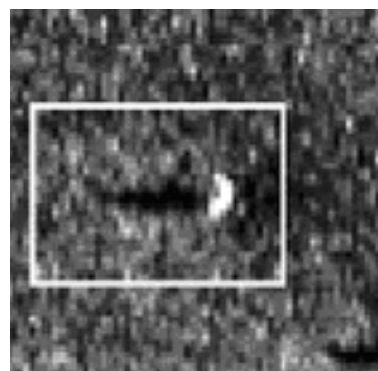


Figure 5. SSI contact snippet.

The SSI is stored in NAVOCEANO's Unified Sonar Image Processing System (UNISIPS) format. Each scan line of the imagery is stored in a separate record, and the latitude and longitude coordinate, the sonar heading, speed, and depth above the seafloor are given for the sample at nadir.

By its nature, SSI is non-linear (Reed et al., 2002). Correlation between pixels in SSI is affected by “speckle” noise (Blondel and Murton, 1997). This speckle noise also hampers the extraction of targets and features in sidescan imagery (Reed et al., 2002). The imagery can contain phantom features created by surface return when the sonar is in shallow water or when the fish is pitched (Kenny et al., 2001). GPS signal dropout at the surface can also cause the imagery processing software to lose scan lines or to duplicate others (Fish and Carr, 1990). Any automated feature detection method that is applied to the imagery must be robust and able to cope with all these issues.

Bottom objects and features can also change and migrate over time due to ocean currents and burial. Even when the objects are stationary, one of the biggest issues with sidescan is position error, often observed to be 15 m or greater during actual surveys (Schwab et al., 1991). The center latitude/longitude position of each scan line in the UNISIPS file includes position error due to GPS error and error from the cable layback model. Because SSS is usually towed through the water with a cable attached to a tow platform, sometimes-large positioning errors are introduced (Schwab et al., 1991, Kenny et al., 2001).

Since GPS will not work underwater, the position of the tow platform, determined by GPS, is first measured, and then the position of the fish is computed by taking into account the length of the cable. If the GPS antenna is not mounted at the same location where the tow cable attaches to the platform, the “antenna offset” must be included in the calculation. If one assumes that the cable is a straight line, the cable length can be computed by using the Pythagorean theorem (Figure 6). In reality, the cable is not straight, and a more complicated equation, called a cable layback model, is sometimes used (Figure 7).

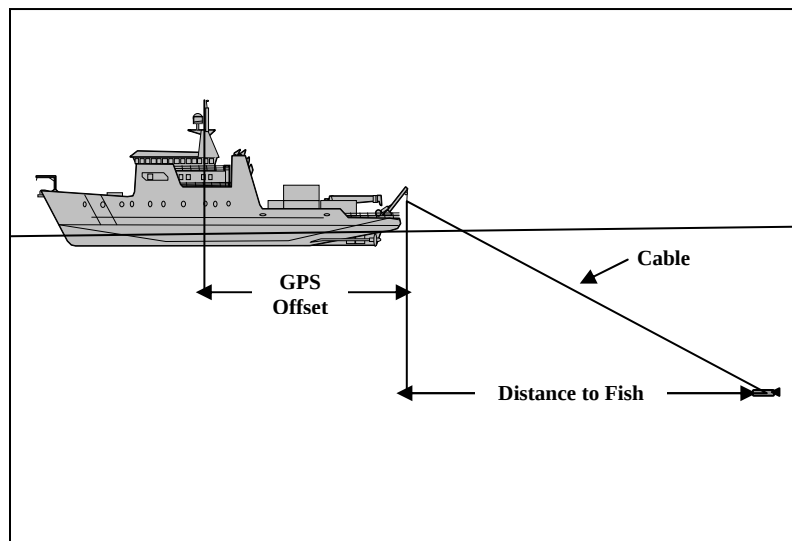


Figure 6. The cable is assumed to be straight.

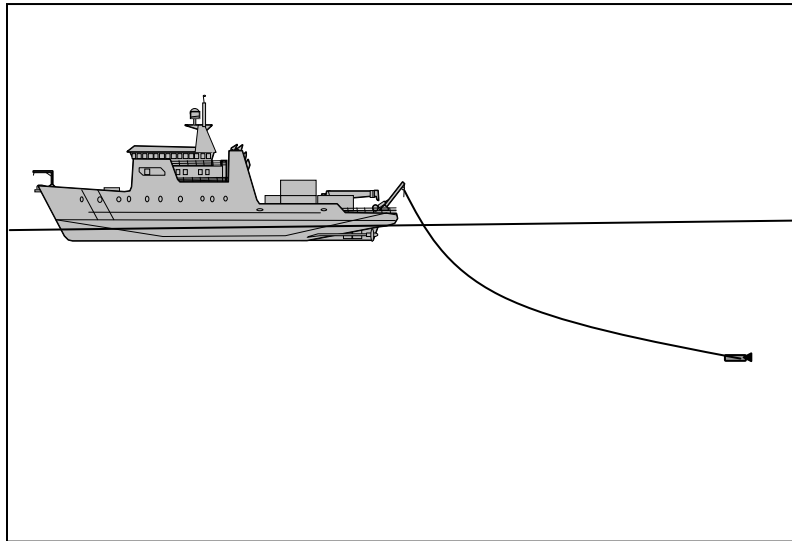


Figure 7. A more realistic depiction of the cable.

Change Detection With Sidescan Sonar Imagery

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Deer, 1995). The term “digital change detection” applies when computer algorithms are used to perform related change detection tasks commonly on data collected by a remote sensing device (Singh, 1989). Digital change detection is a major application of remote-sensed data (Rosin, 1994).

In support of military Mine Warfare (MIW) clearance operations for safe vessel passage, analysts perform change detection by visually comparing historical high-resolution SSI with newly collected SSI in an attempt to identify newly placed objects. The objective of MIW change detection is to match objects detected in new SSI with historical objects stored in a database. Change detection using SSI is potentially a significant time saving tool, but problems such as large data volume, navigational errors, sonar towfish instabilities, differences aspect/orientation, and differences in environmental conditions can hinder the time savings (Lingsch and Lingsch, 2001).

There is an abundance of literature showing the success of the digital change detection on satellite imagery including the ones referenced here (Howarth and Wickware, 1981; Griffiths, 1988; Stow et al. 1990; Banner, 1991; Lambin and Strahler, 1994). Literature is sparse on digital change detection techniques for SSI, although groundbreaking research by the authors at the NRL and the NAVOCEANO in collaboration with the University of New Orleans (UNO) is being conducted (McDowell et al., 2003; Ioup et al., 2003, Ioup et al., 2004). Results from this research and experiments show that automated digital change detection techniques applied to SSI can greatly reduce the time it takes analysts to perform manual change detection. Faster change detection will reduce mine

clearance timelines and allow MIW operators to accurately assess the risk to follow-on naval forces.

ACDC

Over the past few years, the NAVOCEANO has developed software tools and applications to aid analysts in performing manual change detection more efficiently, thus reducing the amount of time needed to identify new bottom objects. NRL working closely with NAVOCEANO, has developed components of a (non-RT) ACDC system including a Computer-aided Detection (CAD) algorithm, Completion algorithm, Computer-aided Search (CAS) algorithm, and Feature-Matching (FM) algorithm.

The final version of ACDC will aid analysts in detecting seafloor features in SSI, classifying and cataloging these features, and comparing them with features “seen” in historical SSI, to determine if the features have moved or are new. A prototype ACDC has been shown to successfully reduce the time to perform change detection, compared with manual methods, while producing similar results (Gendron et al., 2005). Below the key components of ACDC are briefly discussed.

CAD Algorithm

There are a variety of digital change detection techniques including image differencing (Weismiller et al., 1977; Miller et al., 1978; Williams and Stauffer, 1978), image regression (Singh, 1986; Jha and Unni, 1994), and post-classification comparison. The post-classification change detection technique compares two images that were classified independently (Howarth and Wickware, 1981). NRL has applied this technique to SSI, and developed a unique CAD algorithm that is capable of detecting and extracting snippets from historical and recently collected SSI so comparisons can be made later. The CAD algorithm utilizes geospatial bitmaps (GBs) to run in real-time one scanline at a time (Gendron et al., 2001).

Completion Algorithm

The snippets are then sent to a classification stage where NRL’s Completion algorithm attempts to determine if the snippet contains a mine-like contact. The Completion algorithm attempts to determine attributes such as size and shape, and the algorithm then computes a confidence measure. The completion process is not fully automated and prompts the operator to make a final judgment when the confidence measure falls below a set threshold. Figure 8 shows an example of two snippets produced by the CAD algorithm. The Completion algorithm filters the snippet and extracts the shadow. The algorithm then uses the shadow to “complete” the bright spot based on known information such as sonar altitude and the contact’s distance from nadir.

CAS Algorithm

The location of each completed contact is then passed to a CAS algorithm, which queries the MCDB and finds all the historical contacts that are “spatially close” based on an estimate of position error. One factor that can greatly reduce the accuracy of post-classification change detection is the inaccurate geometric registration between the two images (Howarth and Wickware, 1981; Mas, 1999; Singh, 1989). In most cases, the accurate geo-registration of SSI is impossible due to inherent position error. The CAS algorithm uses GBs and a modified quadtree structure to accurately and efficiently perform geospatial searches.

Figure 9 shows a new contact, N_1 , with its associated location error ellipse. In this example, the CAS algorithm determines that H_3 and H_{10} are possibly N_1 observed in the past because the location of H_{10} falls within N_1 's error ellipse and H_3 's ellipse falls within N_1 's ellipse.

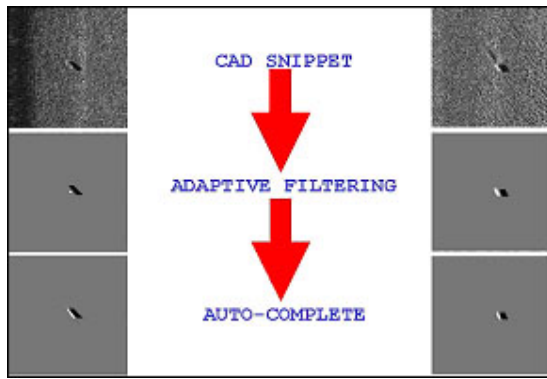


Figure 8. Completion on two different snippets.

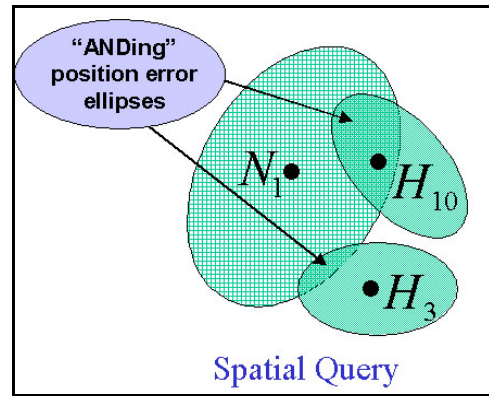


Figure 9. CAS Query.

FM Algorithm

ACDC then tries to automatically “match” one of the historical contacts with the new contact by using an FM algorithm. New objects that are not matched, i.e., not in the database, are identified as “new objects” (change detection). FM algorithm uses a wavelet networks, which in the past have been proven to work well at matching features and are used extensively in face recognition, for example (Krueger and Sommer, 2000).

ACDC-RT

In fiscal year 2005, NRL and NAVOCEANO further developed ACDC into a real-time change detection system (ACDC-RT) and demonstrated the proof-of-concept system during the 2006 JHU/APL Change Detection Experiment. ACDC was not designed to perform change detection without humans, but rather, enable analysts to perform change detection on SSI more efficiently. Digital change detection techniques are useful tools to assist human analysts, and can be useful as a “cueing system” to attract the attention of

human analysts to “interesting” images, but further considerable effort is required to produce fully autonomous change detection systems (Deer, 1995).

To minimize cost and time requirements, NRL and NAVOCEANO used as many of the original ACDC components (discussed above) and change detection software tools as possible. Existing manual change detection software tools included NAVOCEANO’s DHARMA (Data Handling and Real-time Mosaicing Application) and CDFG (Change Detection Further Glance). New components that were developed were a Historical UNISIPS Scroller (HUS) and RT Graphical User Interface (RT-GUI).

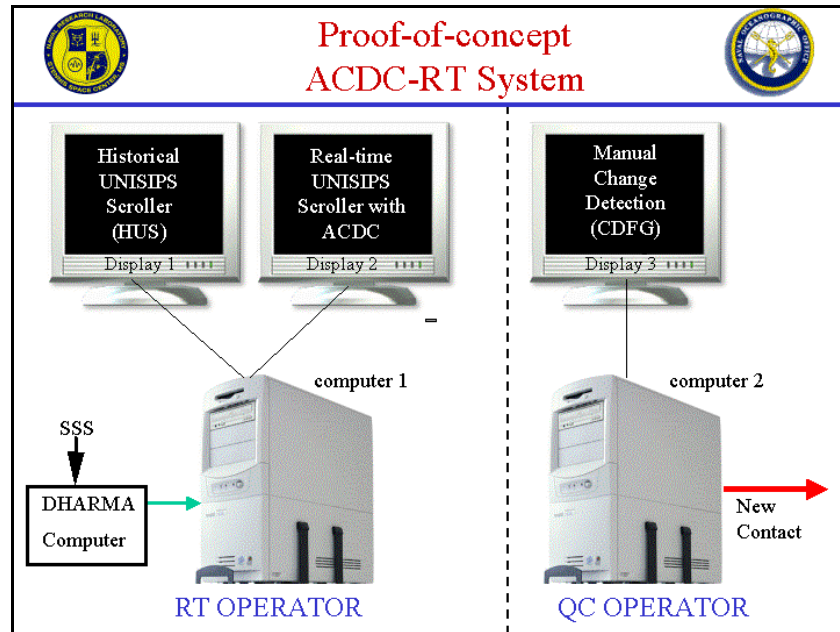


Figure 10. Proof-of-concept ACDC-RT System.

Figure 10 depicts the proof-of-concept ACDC-RT system. The system hardware (all in-house, government-owned equipment) consists of three computers, three displays, and a gigabit network. Display 1 runs a newly developed HUS application that displays historical SSI over the same geographic area (co-registered) as the new survey SSI collected in RT and displayed in the RT GUI. The location of known contacts (i.e., features seen in previous surveys) are plotted in red over the historical SSI, along with the geographic location of the current survey’s sonar. As the sidescan approaches the location of known contacts, the historical contacts automatically pop-up on the same display. The red historical contact markers turn green when the object has been either manually or automatically observed in the SSI from the new survey.

Display 1 requires almost no operator interaction. By simply monitoring the display, the analyst can track where the sonar is in relationship to the historical SSI, which historical contacts are close by, what they looked like in the past, and if they have been observed in the new SSI. To achieve this, NAVOCEANO and NRL modified and integrate relevant DHARMA components into ACDC-RT to perform these tasks automatically.

Display 2 runs the new RT GUI application developed by NAVOCEANO and NRL to display SSI from the new survey as it is being played back in RT. ACDC's CAD and Completion algorithms run on the SSI as it is being displayed. When the algorithms detect a new feature, ACDC's CAS algorithm queries the MCDB to determine if any historical features are spatially close. If so, the new contact and the historical contact(s) are sent to the ACDC's FM algorithm, which attempts to determine if the new feature is one of the historical features. If so, the RT Operator will be prompted to verify the match. If no match is found, the RT Operator will look at Display 1 and attempt to manually match the new contact with a historical contact. The corresponding historical feature marker in Display 1 will turn green if either method produces a match.

If anytime during the collection and displaying of new SSI the RT Operator sees a contact in the new SSI that was not detected by ACDC, the RT Operator can click on the contact in Display 2, at which point ACDC will attempt to complete the object, search the database, and perform the match. The RT Operator can also perform the match manually as described above. As described before, all resulting matches will turn green on Display 1.

Newly detected features that do not match either manually or automatically are provided to the quality control operator (QC Operator) for further verification. The QC Operator performs manual change detection between new and historical SSI. If the QC operator does not observe the contact in the historical data, the operator marks the contact as a new feature (i.e., placed in the survey area after the last survey).

The Experiment

The JHU/APL conducted an at-sea sidescan sonar change detection experiment in May 2006. Several commercial sonars and various methods for near-RT change detection were evaluated. As part of this experiment, NRL and NAVOCEANO demonstrated the ACDC-RT system with three different sidescan sonars.

The survey area consisted of five one-nautical mile long lines in shallow water (20 meters) and five two-nautical mile long lines in deep water (55 meters). Since the set sonar range for the sidescan sonars was 50 meters, the survey lines were spaced at 37.5 meters to allow for 100% overlap. Baseline surveys were conducted by each sonar in the shallow and deep areas, and the location of pre-existing contacts were determined. This information was used to populate ACDC-RT's "historical" MCDB.

Ten objects representing mineshares were then placed over the survey area, with five in the deep portion and five in the shallow portion. Change detection surveys were then run by the sonars. The positions of the newly placed mineshares were unknown to the change detection testing participants. While the change detection surveys were being conducted, ACDC-RT was running and identifying potential new targets. The goal of the experiment was to correctly identify at least 50% of the newly placed mineshares.

Results

After the RT change detection portion of the experiment was complete, ground truth positions for each of the newly placed mineshares were given to NRL and NAVOCEANO. These ground truth positions were compared with the potential new contact positions called by analysts using ACDC-RT. For the typical sidescan sonar, eight of the ten newly placed mineshares were correctly identified by ACDC-RT analysts as new contact. The baseline snippets and the change detect snippets and pictures for some of the correctly identified mineshares are shown in Figure 11.

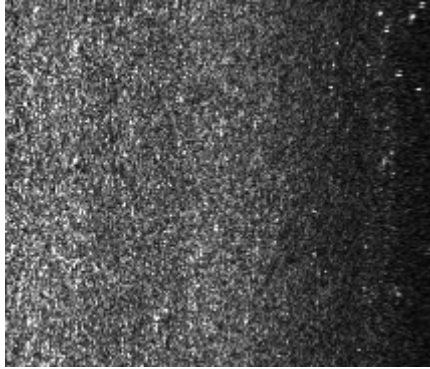
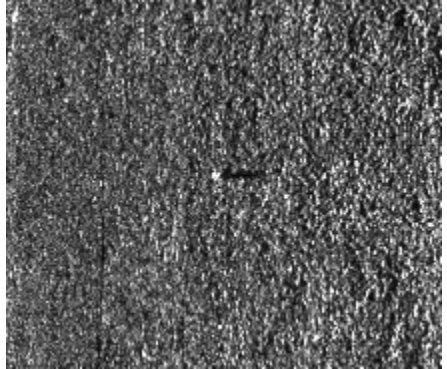
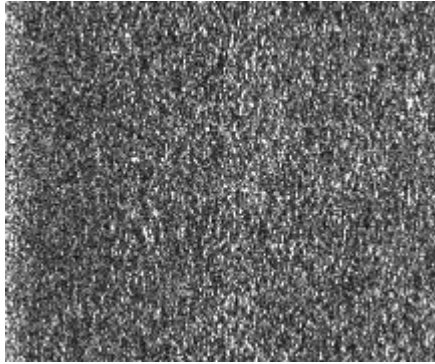
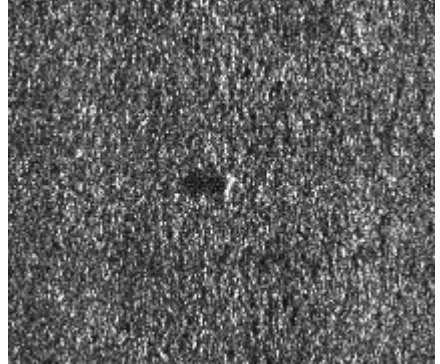
Object	Baseline Imagery	Change Detect Imagery
 Cement-filled 5 gallon bucket		
 Cement-filled plywood box		

Figure 11. Examples of change detections.

Two newly placed contacts that were not identified by ACDC-RT analysts were a cement-filled plywood box and a cement-filled lead pipe. The baseline snippets and the change detect snippets and pictures of these two missed shapes are shown in Figure 12.

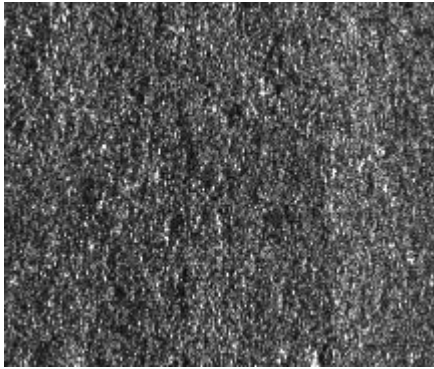
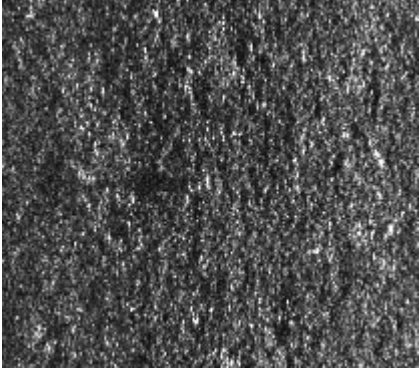
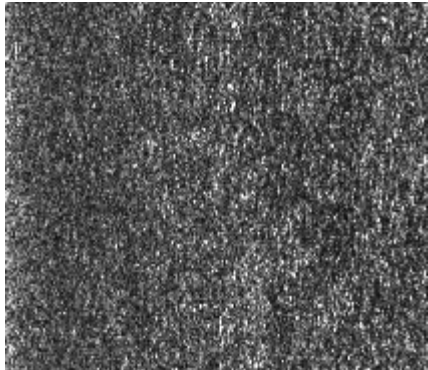
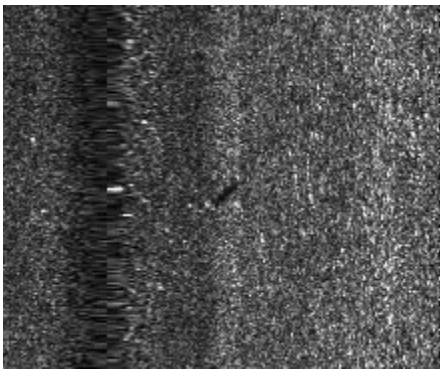
Object	Baseline Imagery	Change Detect Imagery
 Cement-filled plywood box		
 Cement-filled lead pipe		

Figure 12. Examples of missed mineshares.

With typical results of 80% of newly placed shapes identified, analysts using ACDC-RT exceeded expectations of identifying 50% of newly place mineshares.

Conclusion

This paper presents the development and testing of a prototype ACDC-RT system developed by NRL and NAVOCEANO. ACDC-RT aids sidescan sonar analysts in locating proud objects on the seafloor over geographic areas where historical SSI exists. Using ACDC-RT, two analysts can perform “change detection” in real-time, i.e., as the SSI is being collected.

In 2006 during a JHU/APL Change Detection test, NRL and NAVOCEANO successfully demonstrated that sidescan analysis using the ACDC-RT system were able to identify over 50% of mineshares placed in an area after a historical survey was conducted. This was demonstrated using three different commercially available SSS. Analysts using

ACDC-RT were able to find 80% of the newly placed mineshares in RT with one of the sonars.

Two plywood boxes and lead pipes were placed in this experiment. ACDC-RT analysts missed one of each and found one of each; therefore, it is probably not the characteristics (size, shape, material) of the missed mineshares that made them undetectable. Instead, it was more likely the placement of these missed mineshares at the edge of the survey area. Only one scanline of imagery was collected at the boundaries of the survey area as opposed to the overlapping scanlines of imagery collected inside the survey area.

Further funding is required to continue developing and testing ACDC-RT. One key component that is missing is an Area-Matching (AM) algorithm. The AM algorithm will be capable of automatically performing scene matching between historical and newly collected SSI. This can increase the likelihood that a contact observed in the past is the same contact seen in the present if features around the contact are also matched.

Acknowledgements

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