REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
31-JAN-2003	Conference Proceedings, (not refereed)	

4. TITLE AND SUBTITLE
An Introduction To AutoSurvey and Current AutoSurvey Projects

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
0603207N

6. AUTHOR(S)
DONALD L BRANDON BRIAN S BOURGEOIS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
74-7441-E3

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Marine Geoscience Division
Stennis Space Center, MS 39529-5004

8. REPORTING ORGANIZATION REPORT NUMBER
NRL/PP/7440--03-1003

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
SPAWAR PMW 155
4301 Pacific Highway
San Diego, CA 92110

10. SPONSOR/MONITOR'S ACRONYM(S)
SPAWAR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release,distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This paper introduces AutoSurvey, an environmentally adaptive approach to hydrographic surveys, and explains how this new technology can benefit the industry. Also, the paper discusses the effort to integrate AutoSurvey into NAVOCEANO's Integrated Survey System, ISS-60. The AutoSurvey Planner, a new project being developed to bring AutoSurvey functionality to survey planners, is introduced. Results of various comparison tests are presented that demonstrate AutoSurvey's ability to dramatically reduce survey time.

15. SUBJECT TERMS
autosurvey, hydrographic surveys, integrated survey system, autosurvey planner

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
unclassified	unclassified	unclassified	unlimited	8	Donald Brandon
					19b. TELEPHONE NUMBER *(Include area code)* 228-688-5245

An Introduction to AutoSurvey and Current AutoSurvey Projects

Donald L. Brandon Jr., Dr. Brian S. Bourgeois

Naval Research Laboratory
1005 Balch Blvd.
Stennis Space Center, MS 39529
dbrandon@nrlssc.navy.mil
bsb@nrlssc.navy.mil

Abstract- This paper introduces AutoSurvey, an environmentally adaptive approach to hydrographic surveys, and explains how this new technology can benefit the industry. Also, the paper discusses the effort to integrate AutoSurvey into NAVOCEANO's Integrated Survey System, ISS-60. The AutoSurvey Planner, a new project being developed to bring AutoSurvey functionality to survey planners, is introduced. Results of various comparison tests are presented that demonstrate AutoSurvey's ability to dramatically reduce survey time.

I. INTRODUCTION

AutoSurvey is a robust set of algorithms designed to improve upon the current methods of running hydrographic surveys. It was designed and developed by the Naval Research Laboratory, located at Stennis Space Center in Mississippi, and C&C Technologies, located in Lafayette, Louisiana. The original mission of AutoSurvey was envisioned as two-fold; to provide autonomy to hydrographic surveys and to complete surveys more efficiently with comparable or improved quality of data using environmentally adaptive methods. Bourgeois et al. [1] describe in detail the necessity for such a system, its primary objectives, and its early use.

Currently, hydrographic surveys are carried out using fixed-spaced parallel lines with modern multi-beam sonar technology. Multi-beam sonar technology provides a swath of sound returns that can cover a 150-degree angular sector or greater, and is perpendicular to the survey vessel's keel. The swath width is directly related to the water depth underneath the sensors at any given time. For example, in areas where the water is very shallow, the swath width will be narrow. As the water gets deeper, the swath width grows. The distance between the planned survey lines is constant, and is generally based on the estimated swath width that results from the minimum water depth in a survey area. The minimum water depth is usually estimated from older charts whose accuracy may be questionable. The fixed line method is used to ensure adequate data coverage; the narrower swath width results in survey lines that are closer together in an attempt to achieve 100% coverage. While this may benefit the survey by reducing data gaps (holidays), it can produce areas of excessive coverage (overages) and thus excessive survey times. Trying to compensate by basing the survey on wider swath widths, thus spacing lines further apart, will lead to holidays in shallower areas. This makes it somewhat difficult to determine appropriate line spacing for a survey, especially over rough terrain, and it is apparent that trying to pre-determine the appropriate swath widths and line spacing for a hydrographic survey is, at best, sub-optimal.

Current hydrographic surveys also demand supervision and interaction from human operators. Verification of data quality, coverage assessment, and sensor/vessel parameter adjustments are all situations in which a human presence is required at virtually all times. Not only is human supervision necessary in these situations, it is usually necessary that the operators have extensive training specific to the system they are using.

AutoSurvey was developed to alleviate some of the complexities that accompany hydrographic surveys. One of the primary goals of AutoSurvey is to automate the survey process. This includes the processes involved with data quality assurance and coverage assessment, as well as generating navigation waypoints. AutoSurvey handles these issues behind the scenes, drastically reducing the amount of human intervention required during the survey process. This allows the surveys to become virtually autonomous.

It is also a primary goal of AutoSurvey to provide the capability for hydrographic surveys to be more efficient. Using information gathered from the most recently run track line, it is possible to calculate the optimal next track line. This line is not necessarily straight, nor is it parallel, because the line is fit to the previous line's swath edge to ensure gapless coverage. Simulator and field test results conclude that AutoSurvey can minimize holidays and increase efficiency over rough terrain, resulting in timesavings well above thirty percent.

The next section introduces the line fitting schemes that allow AutoSurvey to accomplish its objectives. Section III discusses the transition of AutoSurvey to the U.S. Naval Oceanographic Office (NAVOCEANO) for use with its ISS-60 survey software. Section IV introduces the AutoSurvey Planner, a tool to aid survey planners in the creation of environmentally adaptive hydrographic surveys. Section V highlights the results from comparison testing during the NAVOCEANO System Acceptance Test (SAT), conducted during the AutoSurvey transition to ISS-60, and results from simulator runs showing the savings achieved under extreme situations. Section VI is the summary.

II. LINE RUNNING METHODS

In order for AutoSurvey to make hydrographic surveys more efficient, in-situ assessment of bathymetric data must exist. This is necessary due to the variations that exist in oceanic environments. Variations including bottom composition, bottom morphology, sea state, and sea direction all directly affect the achieved coverage of multi-beam bathymetry. Because of the effects these variations have on the multi-beam system, using fixed parallel lines is often an unsatisfactory method of trying to efficiently perform a hydrographic survey. AutoSurvey tries to accommodate these changes in the environment by evaluating the data collected from the previous line. It then uses this information to generate the next optimal track line using one of several line fitting methods.

The simplest of the methods is the Adaptive Parallel (AP) method. It is similar to the current fixed parallel line running methods, the primary constraint being that all lines must be parallel to one another. The difference is that the lines are not evenly spaced, but rather adapted according to the data from the previous line. This is accomplished by finding the minimum swath width data point on the previous line's swath edge and generating the new line according to that point. Fig. 1 shows a series of lines generated using this method.

There are advantages and disadvantages to using the AP method. First, the straight, parallel lines assure that the navigation of the track line is simplified. Also, there is a guarantee that there will be near 100% coverage of quality data. The trade-off for using this method is that it is possible to have areas of overage. Overage means that some areas were redundantly surveyed, and this redundancy will result in longer survey times. This would occur in situations where lines are run while traversing from shallow water into deeper water along a line. The lines would be generated very close together due to the shallow water, resulting in the vessel eventually tracking through the previous swath.

The Linear Regression method is the second method used by AutoSurvey to generate environmentally adaptive lines. This method tries to project the best fit to the swath edge of the previous line using a robust linear regression algorithm. Like

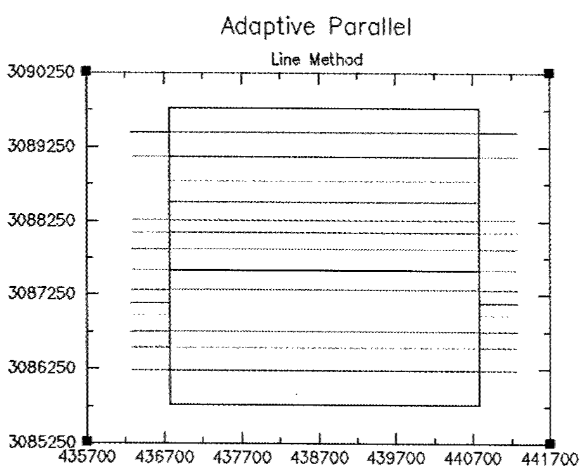

Fig. 1 Lines generated using the AP line method. The coordinate system is in meters. Notice the spacing is not fixed. As water depth gets shallower, the line spacing decreases. Likewise, as the water depth increases, the spacing gets wider.

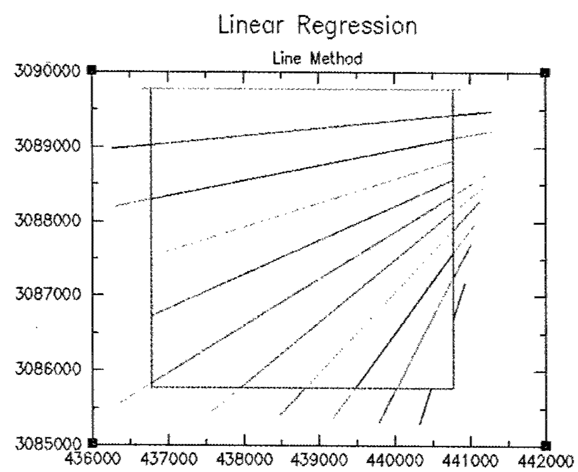

Fig. 2 Lines generated using the LR line method. The coordinate system is in meters. Notice that this method retains the use of straight lines but is no longer constrained to lines that are parallel.

the AP method, the LR method produces a line that is always straight, but the constraint of being parallel to the adjacent lines does not exist. Instead, the line is parallel to the previous line's swath edge. Fig. 2 shows a series of lines generated using the LR method.

This method has the ability to improve survey time, in some situations significantly, since the next line to run will never fall in the previous line's swath. However, data gaps may be introduced and overage could still occur. For example, in areas where water depth varies, excessive coverage may be noticed in deeper waters where the swath width is wider, and as depth decreases and the swath width narrows, data gaps (holidays) may occur. Current development projects to replace the current algorithm with a non-gapping LR method are close to being completed. Until then, the simplicity of navigating straight survey lines still exists with the current LR method. This, in conjunction with the shorter survey periods and the ability to increase the coverage percentage in order to eliminate gaps, makes these situations acceptable.

The final method used by AutoSurvey to generate lines is the Piecewise Linear (PL) method. The PL method is the most complex method used to calculate optimal track lines. The principle behind the PL method is to partition the next line to run into segments of a fixed size and then make calculations on those segments, allowing the contour of the previous swath edge to be fitted and followed. Fig. 3 shows a series of lines generated using the PL method.

Because of its use of segmentation, survey time significantly improves when compared to the AP method, especially over rough terrain. This is because PL calculates the segments to be parallel to

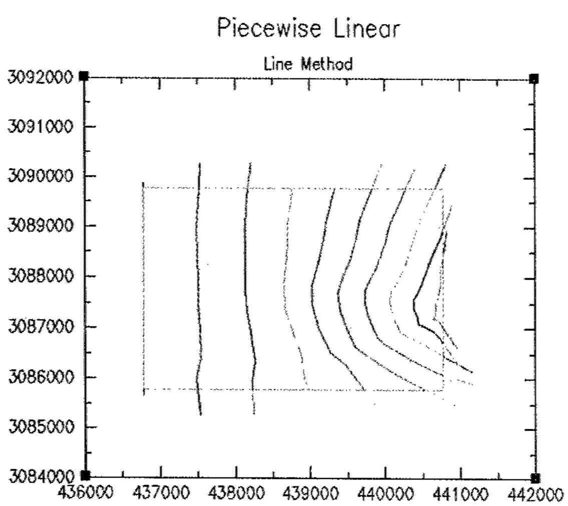

Fig. 3 Lines generated using the PL line method. The coordinate system is in meters. Notice this method is no longer constrained to using straight lines.

the previous swath edge, similar to the LR method. Also, there is noted improvement in coverage over the LR method, since fitting to the swath edge using the shorter segments reduces the possibility of holidays between swath edges.

The primary disadvantage to the PL method is the potential for complicated navigation due to the non-straight nature of the generated track. In areas where the terrain is rugged, extreme variances in depth can create lines that are difficult to navigate. Current research for AutoSurvey software enhancements include defining methods to account for these situations.

It is worth noting that swath edges generally contain areas of poor data quality. Because it is unavoidable to have such areas along the extremities of the swath, coverage overlap is usually necessary. AutoSurvey addresses this situation by providing the ability to specify a coverage percentage. Specifying a coverage percentage enables AutoSurvey to shift the next line to run in order to eliminate unwanted data exclusion areas. For example, specifying 100% coverage in a survey will line up the swath edges, while specifying 200% coverage will put the next line to run along the previous swath edge. This functionality is available with all line running methods.

III. TRANSITIONING AUTOSURVEY

One of the overall objectives for the development team has been to establish AutoSurvey as an essential piece of the survey toolkit. In order for this to occur, it had to be come a mature, robust, and sophisticated component, capable of integrating into and interacting flawlessly with equally sophisticated survey software. To accomplish this, AutoSurvey was tested and enhanced on several platforms before its introduction to NAVOCEANO's ISS-60 software. The two platforms that were used in the early stages of AutoSurvey development were the Oceanographic Remotely Controlled Automaton (ORCA) [2], and the Environmentally Adaptive Navigation (EAN) Simulator [3].

The ORCA was the first test platform for AutoSurvey development. It was an untethered, submersible vehicle, approximately 10m in length, which ran just below the surface of the water. The initial testing on the ORCA was in May of 1997 in the Santa Rosa Ridge area, located approximately 20 miles south of Pensacola, Florida. The goal of this early sea trial was test the flexibility of the three line generating methods. The area provided excellent variation in depth and areas of extreme changes in contour, which provided results proving the efficiency of environmentally adaptive line generation. Two more sea trials over the following year brought the ORCA to the *"hands-off"* level desired by the development team. In August of 1998, the ORCA completed its first simple autonomous survey. The early tests from this series of sea trials returned promising results and prompted the development of a simulator.

Development of the EAN simulator (Fig. 4) began early in 1999 as a joint effort between NRL, C&C Technologies, and Planning Systems, Inc. (PSI), located in Slidell, LA. Its purpose was to offer a tool that can be used to simulate autonomous swath sensor survey missions given vessel and sensor characteristics, and to function as a survey-planning tool. It was also visualized as eventually being transitioned into vessel control systems for various Unmanned Underwater Vehicles (UUVs).

The EAN simulator has been used extensively in-house for many projects that support continuing development of AutoSurvey. It is used to create and run autonomous surveys when given a Digital Terrain Map (DTM) and swath sensor specifications. The data from these surveys can then be used to create graphical images of the areas using third party software.

During the same period that work was beginning on the EAN simulator, another AutoSurvey project commenced. This was the integration of AutoSurvey into NAVOCEANO's ISS-60 survey system. ISS-60 (Integrated Survey System), is a software package supplied to NAVOCEANO by SAIC and is used for various oceanic surveys. It is installed on the TAGS class research vessels and the Hydrographic Survey Launches (HSL). Through a series of simulator demonstrations for NAVOCEANO and sea trials aboard their research vessels, AutoSurvey has matured into a robust library of algorithms ready for transition to NAVOCEANO's survey fleet.

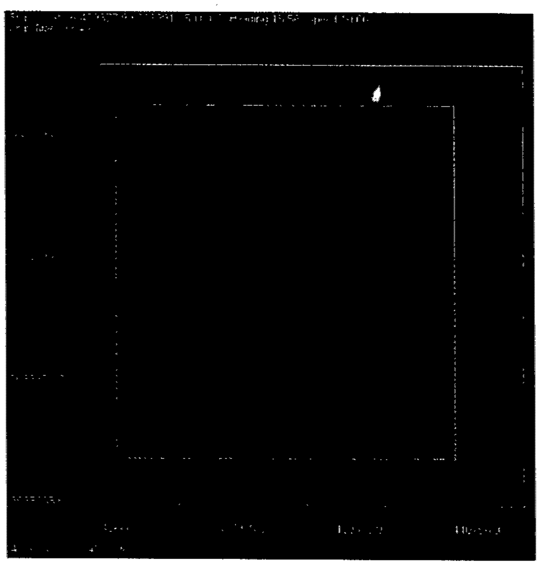

Fig. 4 A screen capture from the EAN Simulator. This is a PL survey of the East Flower Garden Banks area. The coordinate system is in meters.

The introduction of AutoSurvey to NAVOCEANO came in May of 2000 and consisted of a demonstration at their simulation facilities located at Stennis Space Center, MS. The demonstration was successful enough to warrant a series of sea trials to explore the possibilities of making AutoSurvey a permanent part of their survey system.

The first sea trial aboard a NAVOCEANO HSL took place several weeks after the simulator demo. The HSL was a 34-foot, mission ready vessel equipped with a Simrad EM3000 multi-beam sonar system and loaded with the most recent version of ISS-60. The sea trial, which took place out of Gulfport, MS over the three-day period of 22-24 May 2000, was conducted in the shallow water of the Mississippi Sound. The primary mission of this first sea trial was to establish that the AutoSurvey libraries could be integrated into and called from the ISS-60 software (Fig. 5). Once this was established, two days were spent testing AutoSurvey, including how well it handled the different line running methods, its ability to generate waypoints and then send these waypoints to the autopilot. The results of this sea trial were encouraging, but ascertained that system upgrades and enhancements to the algorithms were needed to improve the integration of AutoSurvey into ISS-60.

In November of 2000, the integration effort was shifted to the larger USNS Heezen, a TAGS 60 class research vessel that was better equipped to test the full range of features of AutoSurvey. The Heezen is equipped with a Simrad EM1002, a multi-beam sonar system operating at a frequency of 93 KHz and covering depths up to 800m. This, and the deep-water capability of the vessel, allowed testing to be done in areas and depths that were unreachable by the smaller HSL. The sea trial was conducted in the 300-fathom contour area located along the continental shelf, 60 miles south of Gulf Shores, AL. This area provided deep water, wide swath widths, and the contours of the continental shelf. These conditions were ideal for testing the line fitting

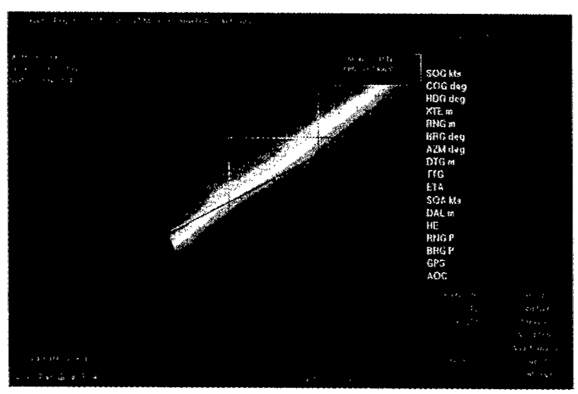

Fig. 5 A screen capture of an AutoSurvey mission running in ISS-60. The survey area was 20 miles south of Pensacola, FL.

methods of AutoSurvey and provided positive survey results. Shallow water tests were also conducted in an area north of the 300-fathom contour area that also provided insight to needed enhancements to the system. The size of the research vessel, for instance, revealed maneuvering issues that were not present with the smaller ORCA vessel and the HSLs. This led to improving the methods used to align the vessel with the next track line.

Two other sea trials during the summer of 2001 proved most useful in further enhancing the AutoSurvey system. The trials were conducted onboard HSLs out Gulfport MS, near the Ship Island channel, approximately twelve miles offshore. Here, the nominal swath width was 17m, increasing to 52m across the channel. The goal of the sea trials was to test various upgrades since the November sea trial aboard the Heezen. Also, during the first sea trial, new issues were discovered. These issues were brought to the attention of the development team and fixes were applied before the second sea trial.

Many upgrades were implemented during this period including modifications to the core library functions. These modifications allowed increased accuracy in performance of the different line generating methods. Also, many enhancements were developed to ease user interaction with the system. User enhancements that were developed included the ability to stop/start unfinished surveys, the ability to change line methods on the fly, and the ability to reverse the waypoints to run lines in the opposite direction. Also, the users were now able to create multiple surveys under a single survey plan, as well as force acquire the next waypoint in the event of navigational errors and to force data logging.

In February 2002, a test plan was proposed to survey and software experts from NAVOCEANO. It was designed to test all of the capabilities of AutoSurvey including line generation waypoint generation, the passing of waypoints to the autopilot, the handling of bad swath data, and the handling of interrupted surveys. Also, the user enhancements that had been added to simplify operator interaction were represented. It was designed as a series of small surveys, each of which tested a different aspect of AutoSurvey capability. This test plan would be the basis as to whether AutoSurvey was ready to be integrated into ISS-60 permanently.

Sea trials to test and finalize the test plan took place offshore of Pensacola, FL onboard an HSL, starting February 16 and ending February 22. The sea trial lasted for six days, by far the most extensive testing done to the system at a given time. NAVOCEANO experts were pleased with the outcome of the test plan and a final sea trial was planned for System Acceptance Testing (SAT) for the transition of AutoSurvey.

In August of 2002, the three-year old effort to transition AutoSurvey to NAVOCEANO for use with the ISS-60 Software concluded with a successful SAT. The Sea trial took place onboard the USNS Mary Sears (TAGS-65), 110 mile west of Key West, FL. The test plan took approximately seven hours to complete.

Following the SAT, comparisons tests were run over a large area in order to analyze time saving between the different line methods and coverage achieved. The area covered offered a new challenge for AutoSurvey, as a 70m drop-off offered a potential "blind spot" for the system. AutoSurvey was able to cover the drop-off well with its AP method. The LR method and the PL method handled the area well when compared to the ladder (fixed, parallel line) method.

With the successful SAT and comparison testing done during the August 2002 sea trial, AutoSurvey was accepted for transition into NAVOCEANO's research fleet. The development team is currently awaiting its final integration into the next release of ISS-60.

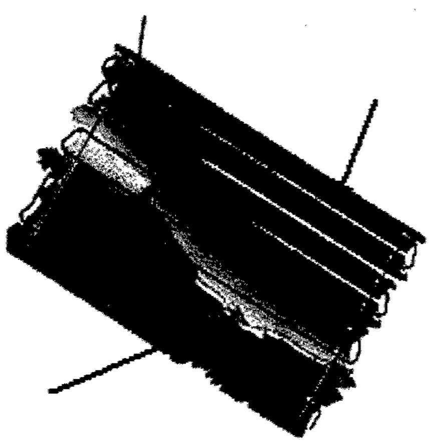

Fig. 6 An image of the ladder survey from the comparison tests near the Florida Keys, August 2002. The red arrow points to a holiday due to the estimated line spacing. The black points to the 70m drop-off.

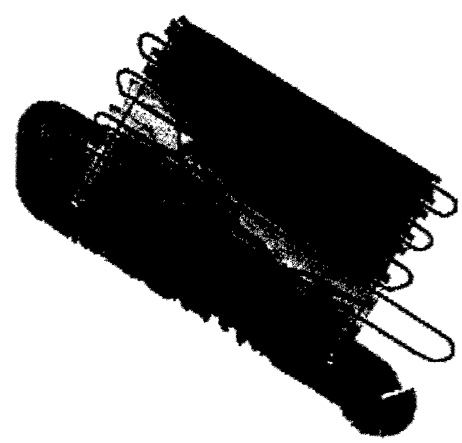

Fig. 7 An image of the AP line method from the comparison test near the Florida Keys, August 2002. Using the AP line method allowed the holidays to be removed, even around the 70m drop-off.

IV. THE AUTOSURVEY PLANNER

With the transition of AutoSurvey to the NAVOCEANO fleet near conclusion, the majority of attention for future development has turned towards a new project, the AutoSurvey Planner. The objective of this project is to provide AutoSurvey to the NAVOCEANO survey planners.

Current pre-mission planning utilizes fixed parallel lines based on the minimum swath footprint of an area to be surveyed. This footprint is determined from assumed vessel and sensor performance, nominal environmental conditions, and the minimum depth in the survey area. By considering vessel and sensor dynamics, using the best bathymetric data available, and by removing the fixed parallel line constraint, it would be possible to apply a dynamic approach to mission planning.

Development on the AutoSurvey Planner began in 2001 to provide realistic survey simulation capabilities to survey planners. The development team from NRL, C&C, and PSI are working to supply NAVOCEANO's Survey Operations Center (SOC) the ability to accomplish dynamic mission planning by incorporating AutoSurvey into their current survey planner. This tool will not only allow them to create efficient surveys, but will provide them the means of viewing and adjusting mission parameters before moving the mission to the field.

The first year of development of the AutoSurvey Planner will focus on moving the processing of data from an interactive mode to a batch mode. Previous projects such as the EAN simulator and the ISS-60 transition project both involved real-time interaction with operators. The proposed concept of how the AutoSurvey Planner will operate is to supply mission specifics to it and let it process uninterrupted. The batch mode concept is necessary due to the potentially long processing times that may exist, depending on survey size and grid size.

Current circumstances require that the AutoSurvey Planner and the SOC's current survey planning software, the Survey Planning Survey Tracking System (SPSTS), run on separate machines. This is due to the SPSTS being a Windows based application and AutoSurvey being UNIX based. Future project goals will most likely include an AutoSurvey port to Windows.

In the meantime, the sharing of information between systems will be handled by file sharing. The AutoSurvey Planner requires certain information from the SPSTS system in order to create the mission it will run. Necessary input from SPSTS include the survey and boundary, the first line to run, and bathymetry data. Other information necessary for the AutoSurvey Planner to run includes vessel and sensor specifications, and vessel speed. These additional parameters are all user-settable before the mission is run.

After the AutoSurvey Planner has processed this information, the resulting data can be exported into various file formats for the end users. This stage of development has been a prime area of discussion as to what formats should be available. Possible file formats, may include .asc for ArcView use, .m for MatLab use, or .tiff for viewing the data as images. The data returned to the SPSTS will include the waypoints generated by AutoSurvey, the vessel track, sensor data coverage, and the survey statistics. The coverage percentage of the survey and hits/bin will be available. The survey statistics being returned will include the amount of time the vessel was inside the survey bounds, the amount of time the vessel was outside the survey bounds during alignment and turns, the total time of the survey, and the area inside the survey bounds.

Future goals include full software development and NAVOCEANO testing for 2003, and a final acceptance test and transition proposed for 2004.

V. NUMERIC RESULTS

AutoSurvey testing has yielded some very promising results since it began in 1997. Most recently, comparison tests were run using AutoSurvey during the SAT for its transition to NAVOCEANO. The test area for these comparison tests was approximately 110 miles west of Key West, FL. The specific survey area was located at 24° 42' N, 083° 42'W (northwest corner of survey area), with a line length of 6,000m and an area width of 4,000m. The depth in the area ranged from 60m to 220m, and the area contained a substantial 70m drop-off as well as more nominal slopes. The drop-off offered a challenge to the system because the grazing angle made it difficult to get returns across the escarpment.

	% Coverage	Line Length (m)	Line Length Savings
Ladder	98+	72556	Baseline
Adaptive Parallel	98.53	59634	18%
Linear Regression	97.35	46434	36%
Piecewise Linear	98+	50050	31%

Table 1. Results from the comparison tests that were run during the ISS-60 SAT, August 2002, near the Florida Keys. The Surveys all had comparable coverage percentages to the ladder survey, but at lower time costs.

The comparison test followed a plan used for earlier tests of the same nature. A survey using fixed, parallel lines would be created as a baseline survey. Comparisons in coverage efficiency and time efficiency would then be made with surveys in the same area using the three AutoSurvey line methods.

The fixed line survey, or ladder survey, was based on a swath width estimate of 500m. At this line spacing, seven lines were created to complete the survey. However, gapping occurred due to a high swath width estimate and in order to fix the survey, additional lines were needed to fill in the area. Also, the 70m drop-off is clearly visible using this fixed line method (Fig. 6). Without the additional lines, coverage percentage for this survey was 95.18%. Filling in the survey area with four additional lines increased the coverage percentage to over 98%, but also increased the total line length to 72,556m.

Using the ladder survey as the baseline, it is clear to see how all of the AutoSurvey line methods offered some level of improved performance. The AP method used 9 lines and a total line length of 59,634m to provide a coverage percentage of 98.53%. Fig. 7 shows how well the AP method handled the 70m drop-off, clearly proving itself as the method of choice for these conditions. Table 1 shows the comparisons of percent coverage, total line length, and timesavings for each of the four methods used.

In the summer of 2002, the EAN simulator was used to run several simulated surveys of the East Flower Garden Bank area. The East Flower Garden Bank area is located approximately 110 miles south of the Texas/Louisiana coastline. It is an area composed of coral reefs and salt deposits that ranges in depth from 18m to 140m, and offers fairly steep contours in some areas and features such as sea mounts in other areas. Results from these

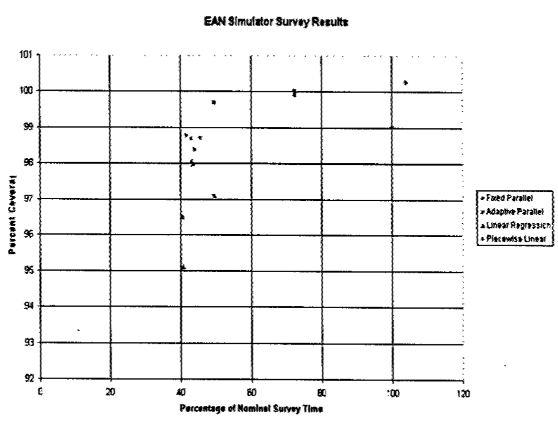

Fig. 8 EAN simulator results from a series of surveys in the East Flower Garden Bank area. Notice the tight group for the PL method, showing how consistent the method can be. The fixed line survey was based on the swath width related to the minimum depth (18m), which allowed the extreme differences in survey times to exist.

simulations were collected and used for similar comparison testing.

Using the EAN simulator, a total of 14 surveys were run to demonstrate how the different line running methods of AutoSurvey were affected by orientation. Because of the extreme changes in depth due to the many features in the area, we were also able to evaluate how efficient AutoSurvey can be in extreme situations. Each of the three line generating methods (AP, LR, and PL) were run using four different starting orientations to the survey area; east-west, north-south, west-east, and south-north. Also, two surveys were run using fixed parallel lines, one with north-south orientation and the other with east-west orientation. The area for all surveys was 4000m x 4000m, and all surveys shared the same parameters. The surveys used a coverage percentage of 100%.

The line spacing for the fixed parallel surveys were based on the minimum depth of the survey area, and the angular sector of the multi-beam sonar. Since the extreme eastern side of the survey area included the seamounts, the line spacing was 18m and offered dramatic differences in method results. When comparing the AutoSurvey results with the pre-planned results of the same orientation, the efficiency of AutoSurvey was clear. The pre-planned survey required a total of 28 lines to complete the survey, and the total survey time was over 6 hours inside the survey bounds. In comparison, the AP method required 15 generated lines to complete the survey in 4.45 hours, and the LR method required 10 generated lines to complete the survey in 2.66 hours. The PL method resulted in numbers similar to the LR method. The same type of results occurred with a north-south orientation.

Fig. 8 shows a scatter plot for this series of surveys. It displays the results of the individual surveys by measuring the time spent inside the survey bounds and the percent of coverage of each survey. The fixed parallel surveys were the basis for the nominal survey time, and the other line running methods were displayed as a percentage of that nominal time needed to complete the surveys. The extreme reduction in survey time when switching line methods from the fixed parallel method is due to the extreme change in depth in the area, the fact that that the fixed parallel survey was based on the shallowest depth, and the fact that AutoSurvey is environmentally adaptive.

The scatter plot also shows how orientation affects a survey. The symbol for each method that is lowest in percent coverage was run with a south-north starting orientation, while the symbol denoting the highest percent coverage was run with an east-west orientation.

VI. CONCLUSIONS

AutoSurvey was developed to contribute to the technology of hydrographic surveys by creating a "hands-off", autonomous approach to surveying, and to provide a means of surveying more efficiently. Its goal is to provide 100% coverage of quality data in less time by generating environmentally adapted optimal track lines according to the previous line's collected data.

The chronology of the AutoSurvey development includes extensive testing on several platforms including the ORCA, the EAN simulator, and vessels in NAVOCEANO's fleet. This testing has led to many improvements to the system, resulting in a very robust and mature set of algorithms that has recently been transitioned to NAVOCEANO for use in its ISS-60 software. The future objectives for AutoSurvey include the transition of the AUTOSURVEY PLANNER to the SOC for dynamic mission planning, as well as transitioning the technology to a survey AUV as part of the ONR Autonomous Operations Future Naval Capabilities (AO FNC).

ACKNOWLEDGEMENTS

This work was funded by the Oceanographer of the navy via SPAWAR under Program Element 0603207N, Dr. Ed Mozely, Program Manager. The mention of commercial products or the use of company names does not in any way imply endorsement by the U.S. navy. Approved for public release; distribution is unlimited. NRL contribution number NRL/PP/7440--03-1003.

REFERENCES

[1] B. Bourgeois, A. Martinez, P. Alleman, J. Cheramie, and J. Gravely, "Autonomous Bathymetry Survey System," *IEEE Transactions Journal of Ocean's Engineering*, vol. 24, No. 4, pp. 414-423, Month 1999.

[2] B. Bourgeois, M. Kalcic, and M. Harris, "ORCA – Oceanographic Remotely Controlled Automaton", *The Hydrographic Journal,* No. 79, JAN96, pp 3-11.

[3] P. McDowell, B. Bourgeois, J. Cheramie, J. Gravely, "Objective Based Dynamic Navigation Planning", *Proceedings of the 12th Intl. Symposium on Unmanned Untethered Submersible Technology*, August 27-29, 2001, Durham, NH.