POTENTIALS AND IMPEDIMENTS FOR OPERATIONAL REMOTE SENSING OF SMALL RECREATIONAL VESSELS

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ABSTRACT

The need to gauge the practicality of remote sensing to monitor marine surface vessels, to examine the accuracy, efficiency, and applicability of currently known detection algorithms, and to evaluate methodologies designed to enhance the integration of spectral and spatial filters to detect, identify and classify surface vessels into general class categories has never been greater. Field surveillance is a widely used method used to obtain this information. However, in situ observation is time and resource intensive as well as fiscally inefficient for agencies whose broadening missions and budget constraints compromise effectiveness. Remote sensing using space based optical sensors is an alternative technology that could more efficiently provide this information, especially when vessel targets are small and potentially numerous.

In this paper we examine the subject of remote sensing as used by coastal maritime agencies in North Carolina to determine what methods of observation are used in connection with monitoring surface vessels in coastal waters. Secondly, alternative data and methods for detecting small recreational vessels using space based high resolution optical systems are explored and compared. Finally, prior published techniques for vessel detection (e.g., in Canada, Pegler et al. 2007) will be examined for the applicability of those techniques in the optically complex waters of the North Carolina Albemarle-Pamlico Sound, a site where recreational and commercial fishing vessels commingle.

Keywords: remote sensing, marine transportation, vessel detection, IKONOS

INTRODUCTION

There are numerous examples of remote sensing application to small object detection in engineering, the geosciences, geography, planning, infrastructure control, near shore fixed object mapping, and homeland security. On the other hand, the field of small vessel detection has only recently been actively investigated. While important in surveillance, small vessel detection has potential as a decision support tool for state and federal government agencies. Selected areas where this support might be applied include:

- regulatory enforcement activities by state and federal agencies such as monitoring commercial fishing,
- environmental hazards monitoring involving fuel discharge, point source pollution control, illegal dumping, etc.,
- vessel traffic congestion as well as vessel traffic pattern analysis/prediction by port authorities,
- local and state government marine surveys and related inventory control systems such as recreational and tourism based marine vessel traffic pattern analysis,
- state and federal government planning for shore based facilities that service the boating industry including the harbors, marinas, boatyards, tourist attractions, etc.,
- United States Coast Guard (USCG) planning with respect to base locations that effectively and efficiently balance cost verses mission,
- local and state government topographic mapping of navigation and marine features boating ramps and access points, pier structures, piles or pilings, breakwaters, and related marine navigation hazards, and
- commercial sea safety services such as TowBoatU.S., SeaTow, etc. that provide non-life threatening boating incident and search rescue operations.

Today, in part exacerbated by the current global economic climate, federal and state budget constraints have created a renewed interest in cost efficient, effective space based optical and GIS solutions that address traditional coastal management issues; issues that will have significant impact on the recreational and commercial boating community. As noted in the Coastal Services journal, "The bulk of existing geographic information used for coastal planning stops at the water's edge. [New methods] can be used to support future planning efforts to maintain recreational boating access and site new boating infrastructure in a way that sustains the estuarine environment" (Sideman, C., 2008). Additional research in this area creates opportunities that may open the door to new techniques and methodologies that will offer commercially available, cost effective solutions that address these needs at the local, state, and federal level.

BACKGROUND

In North Carolina, the Wildlife Resources Commission[1] (NCWRC) is tasked with waterway oversight and governance, a responsibility that is parallel with but secondary to the federal maritime authority assigned to the United States Coast Guard (USCG). In 2008, the budgets for these agencies were approximately $60M[2] and 8.7B[3] respectively. Unfortunately, from a recreational or commercial boater's perspective, only a fraction of that funding was actually allocated to boating safety, in the case of the USCG, $122M[3] in 2008. This USCG funding is in part generated by the Sport Fish Restoration and Boating Trust Fund (formally Aquatic Resources Trust Fund); a funding source that is allocated by Congress and subject to lobbying by political action committees associated with various recreational and commercial boating constituent groups.

To facilitate their missions, the most commonly acknowledged field surveillance method by local and federal officials is direct observation and monitoring. These in situ observations are by nature time and resource intensive as well as fiscally inefficient. To exacerbate the problem, fiscal allocation reductions as well as asset diversion to other maritime mission priorities such as homeland security operations, drug interdiction, war efforts, and so on have reduced the number of missions needed to effectively conduct these direct observations. On the other hand, remote sensing platforms (excluding imagery that is only available to the military and selected federal government agencies) such as airborne, synthetic-aperture radar (ERS, JERS, and RADARSAT, etc.) and space based optical systems (IKONOS, QuickBird, SPOT, etc.) are available and offer potential resources that could help offset the costs associated with direct observation techniques.

When considering airborne based systems, two factors lessen the likelihood of their use as a direct observation substitute. Those include the availability of aircraft that have been upfitted with appropriate imaging equipment/processing resources and the personnel expense associated with operating the vehicle. Few aircraft of this type are available to local and state governments and even if available (including federal agencies) the costs associated with operating these observational platforms both in terms of fuel and personnel is very high. For these two reasons alone, airborne systems are not generally viewed as an operable solution except in very specific circumstances. However, interest in space based optical approaches has been minimal in the past because the commercially available resolution of such systems was on the order of one meter. This resolution limits the detection of many small vessels since the vessels in this category are by definition only a few meters longer or wider than the resolution limit. (Pegler, K., D.J. Coleman, R. Pelot, and Y. Zhang, 2005). Optical systems are also constrained by visibility, i.e. the desire for cloud free imagery. On the other hand, the literature suggests extensive work in the use of radar imagery in connection with vessel detection primarily resulting from its all-weather capability. In fact, much of the current research seemingly focuses on better methods for differentiating between sea level "noise", as caused by wave action, and detectable vessels. However, significant obstacles still stand in the way of SAR being used as an operational resource. Most notably those obstacles emanate from "past research efforts on automatic target detection in SAR imagery [that] have clearly demonstrated that no single detection algorithm will produce satisfactory results" (Crisp, D.J., 2004). In addition, the resolution of the current generation of synthetic aperture radar sensors is too coarse to be operable outside of the research environment (Pegler, et al., 2003). Collectively, these obstacles contribute to SAR being less than an optimal solution at the present time.

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[1] Source: N. C. Wildlife Resources Commission- http://www.ncwildlife.org/fs_index_05_boating.htm
[2] Source: N. C. Wildlife Resources Commission- http:/NCWRC/Executive_Director.htm
[3] Source: USCG Budget 08: http://www.uscg.mil/FY08_Budget.pdf

This brings us back to space based optical solutions. On the horizon, a new cost-benefit rationale may soon be provided through GeoEye-1. GeoEye-1 is a new commercial imaging system owned by GeoEye Inc., which should be operational by the first quarter of 2009. With a ground resolution of 0.41m in panchromatic mode (1.65m resolution in multispectral mode), ultra-high resolution capability, three-meter geolocation accuracy, and three day revisit cycle (to any point on Earth)[4], GeoEye-1 will provide imagery that is superior to any non-military based space systems currently available. As increased numbers of these ultra-high resolution systems become operational, it is possible that the advantages associated with space based optical systems will meet or exceed the current performance offered by competing technologies.

Space based optical solutions useful within the field of small vessel detection are also benefiting from recent research by Iverson, 1997, Subramanian, 1998, and Pegler, et al. between 2002 and 2007. These researchers have greatly expanded the current body of research knowledge by focusing on techniques that do not use traditional "spectral reference libraries and atmospheric corrections but rather used statistics and weighted distance metrics to detect pixel outliers that could in turn be counted in ways that would categorize those having the greatest frequency as targets" (Pegler, K., D.J. Coleman, and R. Pelot (2005).

Investigation, Experimentation, and Repeatability

The remainder of this paper examines the prior published vessel detection techniques used by K. Pegler, D.J. Coleman, R. Pelot, and C.P. Keller in 2007 in their article describing the development of, "An Enhanced Spatio-spectral Template for Automatic Small Recreational Vessel Detection", Photogrammetric Engineering and Remote Sensing". The technique used in these studies evolved though progressive experimentation using high resolution satellite imagery for marine search and rescue reconnaissance (Pegler, K., D.J. Coleman, R. Pelot, and Y. Zhang, 2003) to a next generation "enhanced spatio-spectral template to detect small recreational boats in IKONOS imagery" (Pegler, K., D.J. Coleman, and R. Pelot, 2005). In that study, Dr. Pegler's research team focused on the use of position and attribute data to identify fifty three stationary recreational vessel targets within Cadboro Bay, British Columbia, Canada (Pegler, et al., 2007). Cadboro Bay area is a geographically protected, calm water harbor near the University of Victoria.

Initial interest in this project arose from the question; can the enhanced spatio-spectral template technique used by Dr. Pegler's research team be successfully applied in the optically complex waters of the North Carolina Albemarle-Pamlico Sound? The Albemarle-Pamlico Sound is an interesting comparison because it represents an active boating area in addition to being a site where recreational and commercial fishing vessels frequently commingle. Further examination raised additional questions about whether the enhanced spatio-spectral template technique would generate similar results when applied to both moving vessels (vessels under way) as well as anchored vessels.

Figure 1. Oriental, NC- Neuse River Study Area.

The initial stages of the investigation began with a careful study of the North Carolina Albemarle-Pamlico Sound for a suitable and comparable harbor to Cadboro Bay. Although an exact geographic match of Cadboro Bay within North Carolina does not exist, knowledge of the coastal NC waterways and a search of the GeoEye image catalog of eastern North Carolina yielded two areas considered to be geographically similar. These included sites near Manns Harbor near Manteo, NC and a Neuse River-Oriental Harbor site adjacent to Oriental, NC. Further examination of the GeoEye image catalog resulted in findings of only two IKONOS images; Shallowbag Bay/Manns Harbor (1-DEC-2001) and Oriental, NC (3-JUL-2002). IKONOS data was desired to, as closely as possible, facilitate a comparative study. Both the Shallowbag Bay/Manns Harbor and Neuse River-Oriental Harbor sites offer protected harbors that serve as "home port" for an active recreational and commercial boating community. While both sites were deemed suitable, the Oriental/Neuse River site offered a greater diversity of vessels, i.e. vessels moored, anchored, and underway, that resulted in its selection

[4] Source: GeoEye, Inc.- http://launch.geoeye.com/LaunchSite/about/

as the site of this investigation.

The general area of study incorporates a 93.4 Square Kilometer area adjacent to Oriental, NC and on the Neuse River. This area is significant to the boating community in part due to its strategic location as a major junction on the Intercoastal Waterway (ICW), between Belhaven, NC and Morehead City, NC. In addition to being known as the "Sailing Capital of North Carolina", this area is also home to two full service commercial marinas and is also the only active commercial fishing port on the Neuse River.

The general methodology of the investigation involved the collection or acquisition of analysis software coupled with the satellite imagery as needed to facilitate replication of the previous study. The primary image analysis software tools and data utilized were ERDAS Imagine 9.2, ESRI ArcGIS 9.3 (ArcGIS), R[5], and the archived IKONOS satellite imagery obtained from GeoEye, Inc as noted above. Imagine and ArcGIS were selected primarily due to the availability of East Carolina University software licenses as well as their generally accepted status as industry standards within the remote sensing community. Licenses for both software applications were provided to the authors by the university. R is a free, open source statistical computing and graphics software environment provided by the R Foundation that is available through one of the foundation distribution CRAN (Comprehensive R Archive Network) mirrors, in this case from the University of California, Berkeley, CA[6].

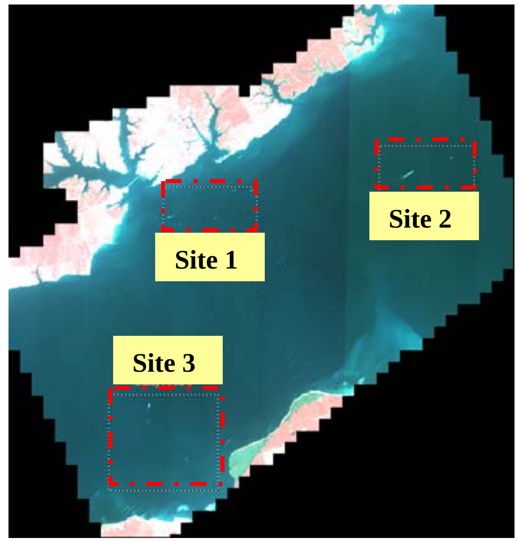

Figure 2. Re-Designed Oriental Study Area(s).

The next phase of the investigation involved dividing the project into three component parts including:

1) evaluating, importing, and sub-setting the IKONOS image data using Imagine into ten zones to facilitate more detailed analysis.
2) reproducing the Euclidean distance metric with weighting performed by an inverse covariance matrix:

$$\mathbf{d^2_{wed} = (x\text{-}m_x)^T C_x^{-1}(x\text{-}m_x)}$$

Figure 3. Vessel Detection in Re-Designed Study Area.

where $\mathbf{d^2_{wed}}$ is the weighted Euclidean distance (WED) metric, **Ec** $\mathbf{C_x}$ = variance – covariance matrix, and m_x = mean vector (Pegler, et al., 2007). This equation was incorporated into an R script that was used to process the study site image subsets using R, and
3) re-importing and evaluating the resulting R-processed files using ERDAS Imagine.

The author's knowledge of this waterway area combined with a close examination of NOAA's Intracoastal Waterway Neuse River to Myrtle Grove Sound Chart (11541, edition: 37, 3/1/2007) lead to the exclusion of Zones 4, 5, 6, and 10. This area is known as "Garbacon Shoal" and is too shallow to support marine vessel traffic. In addition, Zones 2, 7, 8 were excluded due to the minimal presence of observable vessels. The opinion of the authors was that the other zones contained sufficient numbers of stationary and moving vessels to facilitate testing of the vessel detection methods and algorithms used in the previous study.

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5 R is a free open source statistical computing and graphics software environment offered by R Foundation; a not for profit organization involved in public interest projects.

6 Source: R Foundation.- http://www.r-project.org/

Results of Repeatability Testing

During the initial data subset creation/analysis testing phase of this study, it quickly became evident that masking out any land based features was a technique and process prerequisite. Since the initial subset zones did not sufficiently mask out these areas, further subset zone refinements were made to remove these areas from R processing. In addition, during the R analysis process, it was also noted that areas exhibiting even minor specular reflection including river areas adjacent to shorelines with a large number of high intensity pixels were problematic during analysis, i.e. returning images with minimal if any detail. Once these limitations were discovered, the site area was redesigned and more careful selection constraints were applied (see re-designed study area image). The results obtained were matched with those described and illustrated in the original study (see vessel detection as shown in re-designed study area image). In fact, while not specifically measured or included in this investigation, it is easy to observe target profiles and theorize the probable accuracy of determining that part of the high intensity profile attributable to the vessel and that part attributable to the vessels wake. A further belief is that with the development of basic assumptions, reasonable determinations can in fact be made with regard to vessel size and where vessels underway are involved, i.e. the direction of travel.

As an additional test, a four ban IKONOS multispectral imagery was obtained for a small section of Taylor Creek near Beaufort, NC as well as Beaufort Inlet. This area represents a frequently used waterway that also contains large numbers of vessels anchored year round. In addition, the imagery available contained both observable commercial and recreational vessels. With consideration of the Neuse River study area limitations and the findings noted above, it was believed that this area could serve as a useful control check to further test the repeatability of the methods used. The successful result of this test provided further evidence that Dr. Pegler's technique is valid, repeatable, and has applicability in the field of small vessel detection.

Figure 4. Beaufort, NC Study Areas.

Ideally, the findings that would have fully confirmed Dr. Pegler's technique would have been a positive vessel detection test following application of the weighted Euclidean distance (WED) metric method to an entire study area, albeit after land and other high intensity areas were masked out. Unfortunately, neither time nor a suitable masking technique permitted this level of testing at this time. On the other hand, analysis imagery returning no observable targets in areas clearly containing surface vessels would have lead to the erroneous conclusion that such negative results would disconfirm the technique. This did not occur.

SIGNIFICANCE AND CONCLUSION

The impact of the global economic shift, the current state of federal and state fiscal flexibility, the increasing needs for maritime support services, an aging primarily coastal based population that increasing utilizes the waterway as a source of recreation, and our increasing reliance on commercial fishing to supplement the food supply are just a few of the trends that point to the need for increased interest in small vessel detection. Further enhancement of existing vessel detection techniques coupled with the availability of new ultra-high resolution space-based optical systems could lead to a significant improvement over the original studies further serving to benefit the field of small target detection. In addition, this investigation serves to showcase the effective application of space-based technology in ways that benefit the recreational and commercial boating community. As a result, the potential for uncovering operational methodologies that can be used by Federal and State maritime authorities to more effectively monitor surface vessels is predicted to draw increased attention. Finally, the long term benefits derived from the potential development of automated small target detection software that can be easily used by maritime authorities will be of growing interest in governmental and commercial sectors.

In conclusion, it is the opinion of the authors that the significant findings from this study were validation of the weighted Euclidean distance metric algorithm as a legitimate approach for automatically identifying and detecting surface targets using cloudless, 1m, IKONOS, 4 band multispectral images. Further, it is logical to assume that metrics can be developed from observable results that would lead one to make reasonable approximations involving the size and direction (of travel) of targets automatically identified through the this technique. As a result, Remote Sensing (RS) using high spatial resolution satellite imagery in connection with other ground based data could offer an alternative technology that has the potential to supplement traditional reconnaissance missions while simultaneously providing useful waterway information, especially when the marine vessels being monitored are small and numerous. More specifically, the results of this investigation indicate that satellite based optical methodologies can be effectively used by Federal and State maritime agencies to monitor surface vessel traffic, offer enhance maritime safety-security, and provide enhanced services to the recreational and commercial boating communities such as waterway regulation planning, prediction, and enforcement to improved response times to maritime incidents.

REFERENCES

Crisp, D.J., 2004. The State-of-the-Art in Ship Detection in Synthetic Aperture Radar Imagery, Australian Government: Dept. of Defense, Defense Science, and Technology Organization (DSTO), DSTO Scientific Publications Online Repository, No. DSTO-RR-0272, Retrieved December 15, 2008, from http://www.dsto.defence.gov.au/publications/2660/DSTO-RR-0272.pdf.

Iverson, A.E., 1975. Subpixel object detection and fraction estimation in hyperspectral imagery, *SPIE*, 3071:61–71.

Pegler, K., D.J. Coleman, R. Pelot, and Y. Zhang, 2003. The potential for using very high spatial resolution imagery for marine search and rescue surveillance, *GeoCarto International*, 18(3): 35–39.

Pegler, K.H. 2004. A Marine Recreational Vessel Reconnaissance System Utilizing IKONOS Imagery, Ph.D. dissertation, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada.

Pegler, K., D.J. Coleman, R. Pelot, and Y. Zhang, 2005. Comparison of maximum distance metrics for use in the remote sensing of small targets, *Journal of Surveying Engineering*, 131(2): 50–59.

Pegler, K., D.J. Coleman, and R. Pelot, 2005. Automatic small vessel detection utilizing IKONOS, In *Proceedings of 8th International Conference Remote Sensing for Marine and Coastal Environments*, Halifax, May 17-19.

Pegler, K., D.J. Coleman, R. Pelot, and C.P. Keller, 2007. An enhanced spatio-spectral template for automatic Small recreational vessel detection, *Photogrammetric Engineering and Remote Sensing*, Vol. 73, No 1, 079-087.

Rancourt, M. Captain, K. Pegler, D.J. Coleman, R. Pelot, 2002. Development of an IKONOS coverage prediction application, In *Proceedings of The 95th CIG Annual Geomatics Conference/Joint International Symposium on Geospatial Theory, Processing and Applications*, Ottawa, Jul 8-12.

Sideman, C., 2008. Florida capturing recreational boater behavior in a GIS, *Coastal Services*, Vol. 11, No. 5, pp. 6-7.

Subramanian, S., and N. Gat, 1998. Subpixel object detection using Hyperspectral imaging for search and rescue operations, *SPIE*, 3371:216–225.