

PROCEEDINGS OF SPIE

Signal and Data Processing of Small Targets 2015

Oliver E. Drummond
Editor

12–13 August 2015
San Diego, California, United States

Sponsored and Published by
SPIE

Volume 9596

Proceedings of SPIE 0277-786X, V. 9596

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Signal and Data Processing of Small Targets 2015, edited by Oliver E. Drummond,
Proc. of SPIE Vol. 9596, 959601 · © 2015 SPIE · CCC code:
0277-786X/15/\$18 · doi: 10.1117/12.2218385

Proc. of SPIE Vol. 9596 959601-1

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:

Author(s), "Title of Paper," in *Signal and Data Processing of Small Targets 2015*, edited by Oliver E. Drummond, Proceedings of SPIE Vol. 9596 (SPIE, Bellingham, WA, 2015) Article CID Number.

ISSN: 0277-786X
ISSN:1996-756X (electronic)
ISBN: 9781628417623

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Copyright © 2015, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/15/\$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL
LIBRARY**

SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print. Papers are published as they are submitted and meet publication criteria. A unique citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc.

The CID Number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages.

Contents

- v *Authors*
- vii *Conference Committee*
- ix *Signal and Data Processing Workshops*

SESSION 1 SIGNAL PROCESSING

- 9596 04 **Small and dim target detection by background modeling** [9596-3]
- 9596 06 **Numerical study of the statistical characteristics of range-resolved sea clutter** [9596-5]
- 9596 07 **Research on the algorithm of infrared target detection based on the frame difference and background subtraction method** [9596-6]

SESSION 2 TRACKING: ASSOCIATION AND FILTERING

- 9596 09 **Track-to-track association for object matching in an inter-vehicle communication system** [9596-8]
- 9596 0A **Relationship between fractional calculus and fractional Fourier transform** [9596-9]
- 9596 0B **Implementation and performance of FPGA-accelerated particle flow filter** [9596-14]

SESSION 3 SIGNAL AND DATA PROCESSING ISSUES

- 9596 0C **Dim target trajectory-associated detection in bright earth limb background** [9596-16]

POSTER SESSION

- 9596 0I **Detecting ground moving objects using panoramic system** [9596-22]
- 9596 0J **A new geometric constraint method of moving object detection using moving camera** [9596-23]
- 9596 0K **Motion object tracking algorithm using multi-cameras** [9596-24]

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Bogdanovic, Miro, 09
Boyd, John E., xi
Breu, Jakob, 09
Charalampidis, Dimitrios, 0B
Chen, Penghui, 0C
Chen, Qi, 09
Chen, Qian, 0K
Dong, Liqun, 07
Gu, Guohua, 0I, 0J, 0K
Hallenborg, Eric, xxi
He, Xiaoyu, 0C
Hu, Jing, 04
Hui, Mei, 07
Hwee, Peh Chin, xxi
Jaszewski, Martin, xxi
Jiang, Yuesong, 0C
Jilkov, Vesselin P., 0B
Kong, Xiaofang, 0K
Liu, Fan, 04
Liu, Ming, 07
Liu, Xiaohua, 07
Liu, Yun, 07
Lu, Mingfeng, 0A
Roth, Tobias, 09
Sworder, David D., xi
Wang, Jianing, 06
Wang, Jing, 0I
Wang, Wenjuan, 0J
Weiss, Christian A., 09
Wu, Jiande, 0B
Wu, Yijian, 07
Xu, Fuyuan, 0I
Xu, Xiaojian, 06, 0C
Yang, Wei, 0J
Yu, Yi, 04
Yuan, Ting, 09
Zhang, Feng, 0A
Zhang, Yanshan, 0A
Zhao, Yuejin, 07

Conference Committee

Program Track Chair

Khan M. Iffekharuddin, Old Dominion University (United States)

Conference Chair

Oliver E. Drummond, Consulting Engineer (United States)

Conference Co-chair

Richard D. Teichgraeber, Consulting Engineer (United States)

Conference Program Committee

Liyi Dai, U.S. Army Research Office (United States)

Darren K. Emge, U.S. Army Edgewood Chemical Biological Center
(United States)

Denise E. Jones, U.S. Army Space and Missile Defense Command
(United States)

Karla K. Priestersbach, Missile Defense Agency (United States)

Steven W. Waugh, Defense Threat Reduction Agency (United States)

Session Chairs

Signal, Image, and Data Processing Plenary Session

Khan M. Iffekharuddin, Old Dominion University (United States)

1 Signal Processing

Oliver E. Drummond, Consulting Engineer (United States)

Larry B. Stotts, Stotts Consulting, LLC (United States)

2 Tracking: Association and Filtering

Oliver E. Drummond, Consulting Engineer (United States)

Eric Hallenborg, Space and Naval Warfare Systems Center Pacific
(United States)

3 Signal and Data Processing Issues

Oliver E. Drummond, Consulting Engineer (United States)

Eric Hallenborg, Space and Naval Warfare Systems Center Pacific
(United States)

- 4 Workshop: Signal and Track Processing
Oliver E. Drummond, Consulting Engineer (United States)
Eric Hallenborg, Space and Naval Warfare Systems Center Pacific
(United States)

Workshop Topic:
Signal and Data Processing

Presentation Titles:
**Action windows with
resource limits
and
Implementation and
evaluation of a detector of
clutter embedded resolved
targets in optical and
infrared maritime video**

**This Series of Conferences Has
Added A Daytime Workshop.**


**The conference proceedings and the SPIE Digital
Library will use a copy of each author's PowerPoint
file instead of a manuscript.**

Workshop I: Action Windows with Resource Limits

David D. Sworder¹ and John E. Boyd²

¹University of California, San Diego


²Cubic Global Defense Applications, Inc.



ACTION WINDOWS WITH RESOURCE LIMITS

SPIE paper 9596-17
13 August 2015

David D Sworder, University of California San Diego
John E Boyd, Cubic Global Defense



ACTION WINDOWS WITH RESOURCE LIMITS

Abstract

A command algorithm makes resource decisions on the basis of the quality of its location or extrapolation estimates. When resources are expended, they can be distributed in a compact region with a high density. Or they can be distributed across an expanded region. An expanded region increases the capture probability but also expends resources at an increased rate. This paper contrasts the uni-model and multi-model capture regions using the same raw measurement data set. The hybrid algorithm is much more efficient in resource allocation. It employs a confidence index that is used as an enable signal before resources are distributed. Hybrid algorithms improve capture rates with smaller resource demands.

Further author information: (Send correspondence to D.D.S)
D.D.S.: E-mail: dsworder@ucsd.edu
J.E.B.: E-mail: john.boyd@cubic.com

The topic is discussed in detail in the authors' book
Locating, Classifying and Countering Agile Land Vehicles
Springer (to appear August 2015)

2

SPIE paper 9596-17 August 13, 2015

- Target tracking frequently supports tactical decisions in a command architecture
- Real-world actions must recognize constraints:
 - Limited available energy
 - Deployment and location of sensors
 - Detectability of expended energy
 - Processing resources
 - Time
 - Type and quantity of countermeasures
- This paper studies the ability of uni-model and multi-model tracking algorithms to support command algorithms in constrained deployment of sensing and countermeasure

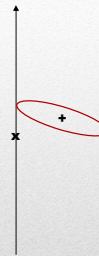
Introduction

3

SPIE paper 9596-17

August 13, 2015

- A target of uncertain intent moves along a road grid
- Emplaced sensors determine range and bearing to the target at regular intervals
- We seek to determine target intent with the aid of a classifying sensor
 - The sensor can be directed to regions of varying size
 - Sensor accuracy is improved if the interrogated region is small
 - If target is classified hostile, countermeasures may be deployed, with greater effectiveness in smaller regions
- Thus, we seek small regions of assured target location
- Action windows (*assurance regions*) are ellipses containing a specified probability of target presence
 - Circular error probable (CEP) is a 50% *assurance region* constrained to equal axes.



x true position
+ estimated position
- 75% assurance region

The Topic

4

SPIE paper 9596-17

August 13, 2015

- Single motion mode
- Standard CV plant dynamics model
- Range-bearing measurements are translated to lat-lon using estimated target position (**extension**)
- Plant noise is augmented to account for nongaussian maneuver modes (**extension**)

Uni-model Estimator: Extended Kalman Filter **5**

SPIE paper 9596-17

August 13, 2015

- Explicitly allows for CV and CT motion
 - Maneuver modes are left (L), straight (S), and right (R)
- Accepts position, modal, or both observations as available
- Models each possible mode history for l time steps
 - For example, an $l=3$ path might be L|L|S -- (27 modes)
- Estimates probability of each modal l -path to generate the composite state estimate (path and position-velocity)
 - Estimator output estimate is a weighted Gaussian sum across all l -path estimates (a wavelet)

Multi-model Estimator: Gaussian Wavelet Estimator **6**

SPIE paper 9596-17

August 13, 2015

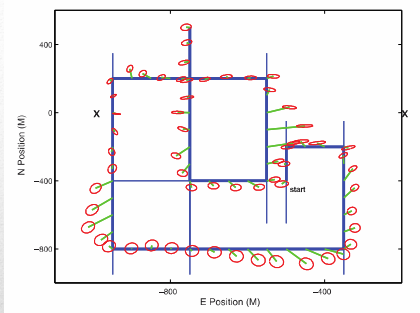
- Each estimator provides an estimate of target position and an estimate error covariance
- To compare estimator performance, we normalize the position error and obtain the unit Gaussian white sequence

$$\tilde{\chi}_E[k] = F_{zz}^{-1}[k] \tilde{\chi}[k] \sim N(0, I)$$
- We refer to the units of norm of $\tilde{\chi}_E[k]$ as σ ; e.g., if the norm of $\tilde{\chi}_E[k]$ is 2, we say the tracker estimate is off by 2σ .
- Action is directed to the interior of a σ -multiple of the centered covariance ellipse.
 - An action window of size 1.18σ should capture the target 50% of the time
- Larger action windows require more power
 - To increase capture probability to 95%, a 2.5σ ellipse is required with more than 6 times the power of a 1σ ellipse
- Comparison statistics are therefore
 - The number of hits (action window actually contains the target)
 - Area illuminated (a measure of required emitted power, detectability, or countermeasures)

Action Window Statistics 7

SPIE paper 9596-17

August 13, 2015



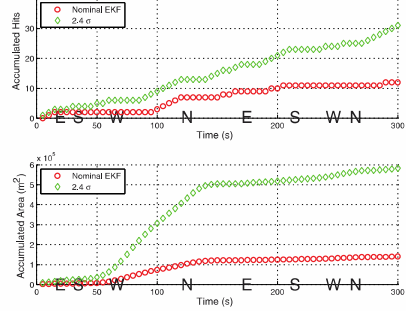
- x marks sensor locations
- Problem: Illuminate the target given tracker position and derived action window estimates

1: TARGET ILLUMINATION 8

SPIE paper 9596-17

August 13, 2015

- 95% coverage is expected from 2.5σ windows.
- Actual coverage achieved is little better than 50%
- Area covered (energy) is more than 4 times that of a 1σ EKF



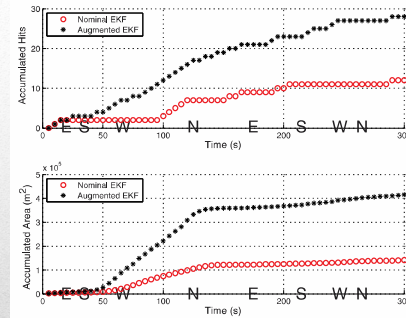
The Nominal EKF Illuminator

9

SPIE paper 9596-17

August 13, 2015

- Pseudonoise improves tracker performance but generates large action windows
- A-EKF windows contain the target about half the time
- It misses 9 straight points (probability of this event is 0.2%)
- It uses 71% of the energy required by the nominal EKF, still large



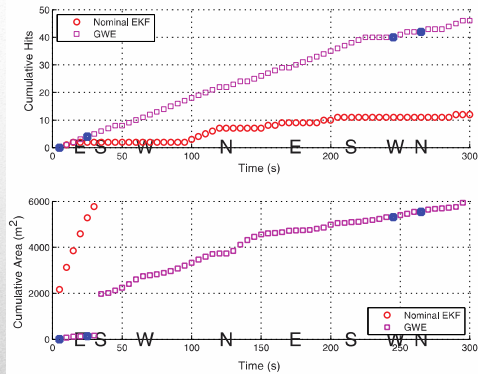
Augmented EKF Illuminator

10

SPIE paper 9596-17

August 13, 2015

- GWE has more information than EKF
 - A crude speed measurement
 - Map-constrained motion
- Compared to nominal EKF,
 - Miss rate is far smaller
 - Energy is orders of magnitude smaller



The GWE Illuminator

11

SPIE paper 9596-17

August 13, 2015

- Nominal and augmented EKFs achieved similar performance with similar energy expenditure
- GWE misses few illuminations
- GWE uses 99% less energy than the nominal EKF

Problem 1 Conclusions

12

SPIE paper 9596-17

August 13, 2015

2: BALLISTIC FIRE CONTROL

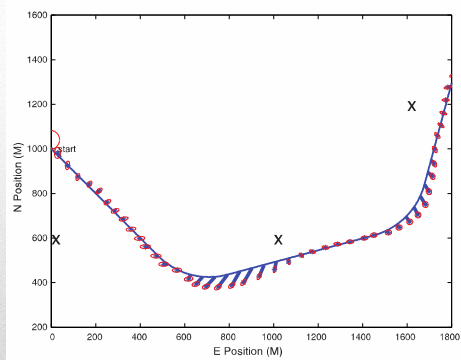
Range measurement error: 2 m

13

SPIE paper 9596-17

August 13, 2015

- A hostile target maneuvers in the plane
- We seek to neutralize the target with ballistic particles having range-dependent time of flight
- The tracker must predict the target position at the time of impact



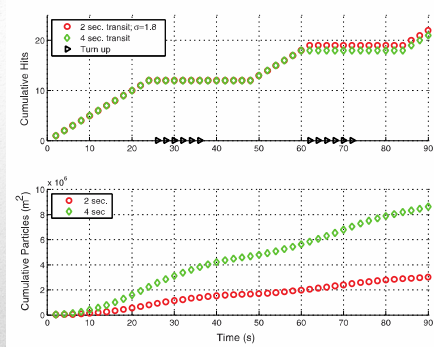
2: BALLISTIC FIRE CONTROL

14

SPIE paper 9596-17

August 13, 2015

- Goal: 95% probability of fewer than 10 misses
 - Leads to 80% cover probability
 - Again, resources are constrained
- Simplifications
 - Fixed 2-s and 4-2 predictions
 - Hit probability is independent of location within action window
 - Cover sequence is iid
- EKF misses are more than double the specified 10
- Over 9 million particles are expended with uniform firing

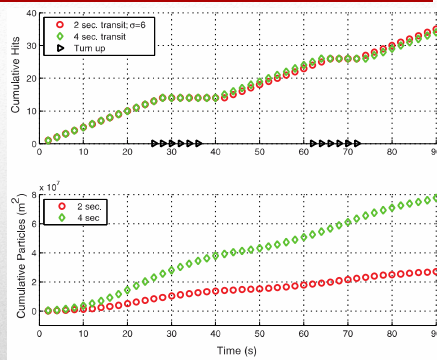


EKF Tracker (1.8 σ -windows) 15

SPIE paper 9596-17

August 13, 2015

- Goal: 95% probability of fewer than 10 misses
 - Leads to 80% cover probability
 - Again, resources are constrained
- Simplifications
 - As before
- The 11 EKF-6 misses nearly meet the spec
- Over 80 million particles are expended with uniform firing

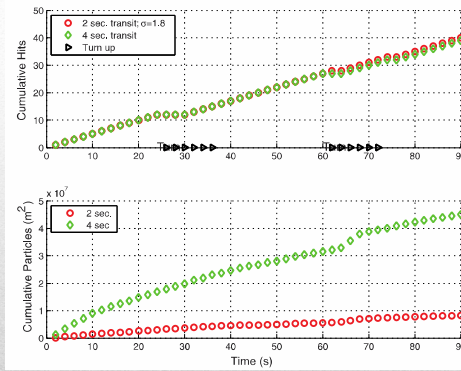


EKF Tracker (6 σ -windows) 16

SPIE paper 9596-17

August 13, 2015

- GWE uses the same measurements as EKF
- Fewer misses (5) than the 6σ EKF (11)
- Expends fewer particles than EKF

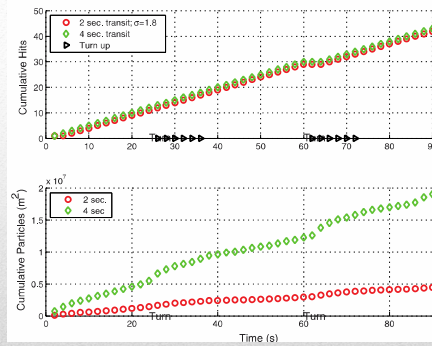


GWE Tracker [1.8 σ windows] 17

SPIE paper 9596-17

August 13, 2015

- Augmented GWE uses more information
 - Modal measurement; 80% correct
- GWE fires on every measurement, using 20 million particles
- Misses 3 times, 2 for the 4-2 predictor



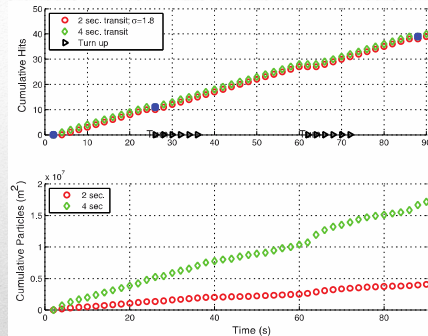
Augmented GWE Tracker [1.8 σ windows]

18

SPIE paper 9596-17

August 13, 2015

- Same GWE, but with modified firing strategy
 - If modal confidence is above 75%, use 1.8σ action window
 - If not, do not fire
- There are three more misses, still fewer than the specified 10
- Particles expended reduced about 25%



Augmented GWE Tracker [fire when confident]

19

SPIE paper 9596-17

August 13, 2015

- A hybrid tracking algorithm demonstrated substantial advantages over the uni-model EKF in both problems studied
 - Location estimates and predictions are much more accurate with the GWE
 - Action windows have higher fidelity
 - Defensive resource expenditure is reduced an order of magnitude
- Use of a para-measurement can further improve the hybrid tracker performance
 - Benefit is more from reduced uncertainty (smaller action windows) than from improved prediction accuracy
- The fire-when-confident strategy further reduced resource consumption at a small increase in number of misses
- The augmented GWE is harder to implement than EKF or GWE, but in applications where particle cost or inventory is considerable, the more nuanced approach may be warranted

Conclusions

20

SPIE paper 9596-17


August 13, 2015

Workshop II: Implementation and evaluation of a detector of resolved targets in cluttered optical/infrared maritime video

Martin Jaszewski*, Eric Hallenborg*, and Peh Chin Hwee**

*Space and Naval Warfare Systems Center Pacific, San Diego, USA


**ST Dynamics Pte Ltd., Singapore, Republic of Singapore



Implementation and evaluation of a detector of resolved targets in cluttered optical / infrared maritime video


Martin Jaszewski*, Eric Hallenborg*, Peh Chin Hwee**
OP150-OP501-21 9596-18
August 13, 2015

Distribution A



Abstract & Overview

- ▼ We implement and test the target detection method proposed in 2014 by Stotts and Hoff [1]
- ▼ The focus of our effort was to explore the utility of the method for scenes containing maritime targets and backgrounds



7/31/2009 2

Abstract Full Text

We implement the method proposed in 2014 by Stotts and Hoff (SH14) [1] to automatically detect resolved targets embedded in background clutter. The SH14 method provides a test statistic which emphasizes comparing apparent contrast rather than signal to noise ratio. The SH14 authors demonstrated through analysis and simulations that their method can detect low or even zero contrast targets in clutter if the background variance is greater than the common system noise variance.

We apply this detector to the maritime domain in which marine vessels are typically found amid clutter such as waves, glint, whitecaps, wakes, port and harbor infrastructure, etc. Our implementation provides an estimate of the common system noise variance whereas SH14 uses a fixed value in their theoretical validation. We estimate the system noise from the video directly without any prior knowledge of the imaging sensor parameters. After considering several noise models with different assumptions about the spatiotemporal variance of system noise we will compare the results to justify our model selection. Further, we provide a means to compute the background statistics needed by the SH14 detector, following the approach in [2] by using a sliding annulus with a guard band and distinct background mean and variance estimation bands.

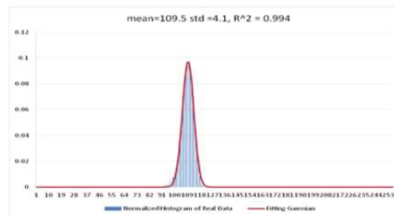
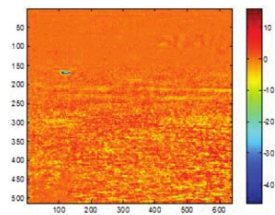
Finally, we will evaluate the detection accuracy of our implementation of the SH14 detector using a video dataset depicting marine vessels in real world maritime environments using the PASCAL VOC Challenge evaluation framework. We will analyze the computational performance of our detector as a function of various input parameters.

7/31/2009

3

Statistical Resolved Target Detection (1/3)

- ▼ Statistical detection aims to make a reasoned and firm decision about the presence/absence of a target based on:
 - Measurements from an image or video frame
 - A statistics based model of noise/clutter



7/31/2009

4

Statistical Resolved Target Detection (2/3)

- ▼ What is “resolved” detection? How is it distinct from the unresolved model?
 - Unresolved target detection assumes that pixels containing targets are composed of Target + Noise + Clutter
 - Resolved target detection assumes that pixels containing targets are composed of Target + Noise, and pixels containing clutter are composed of Clutter + Noise
 - Also known as “extended” targets
 - Used by Stotts and Hoff (2014) for their target detector

Statistical Resolved Target Detection (3/3)

- ▼ What are the key predictions of SH14?
 - Detection performance depends on apparent contrast, not SNR
 - Detection performance depends on background clutter to common system noise ratio
- ▼ What are the open questions?
 - How to obtain appropriate target signature?
 - How to estimate system noise?
 - Can background clutter be modeled as Gaussian?
- ▼ What are the questions we can address by using real-world video?
 - It gives us a path to validate of the theory using incremental crawl-walk approach

Experiment

▼ Goal, Scope

- Explore the utility of the method for scenes containing maritime targets and backgrounds

▼ Methodology:

- Evaluate assumption that background clutter is Gaussian
- Our crawl/walk approach moves past simulated targets in simulated background clutter:
 - Crawl: simulated target in real background clutter
 - Walk: real target in real clutter
- How do our results compare to predictions of SH14?

▼ Limitations?

7/31/2009

7

EO/IR Surveillance Video from Singapore

▼ Electro-optical

▼ IR (short/mid/long-wave)

- Low contrast boats
- Gaussian clutter background

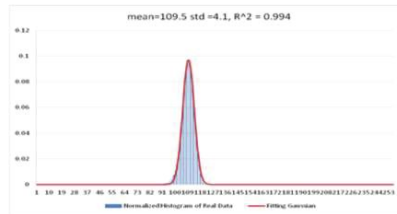


7/31/2009

8

EO/IR Surveillance Video from Singapore

- ▼ Electro-optical
- ▼ IR (short/mid/long-wave)
 - Low contrast boats
 - Gaussian clutter background



7/31/2009

9

Clutter Analysis

- ▼ Analyzed example LWIR and SWIR videos
- ▼ Spatial and temporal
 - 20x20, 40x40, 80x80, 120x120
 - Compare results for single frame vs. averaged across 100 frames
- ▼ Gray level histograms can be adequately approximated by a Gaussian distribution
 - As expected, fit was better when sampling with a larger window and/or across more frames
 - Poorest R^2 measure: 0.854 (1 frame, 20x20 window)

7/31/2009

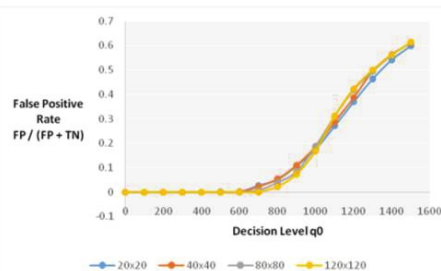
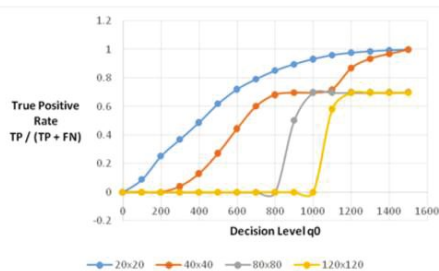
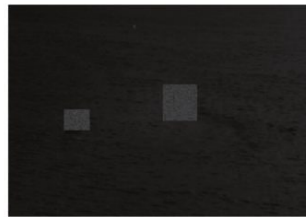
10

Crawl/walk approach

- ▼ Stotts and Hoff (2014) demonstrated their method using a grid of simulated targets on simulated background
- ▼ We used a crawl-walk approach to progressively add more realistic conditions
 - Crawl: simulated target in real background clutter
 - Walk: real target in real clutter

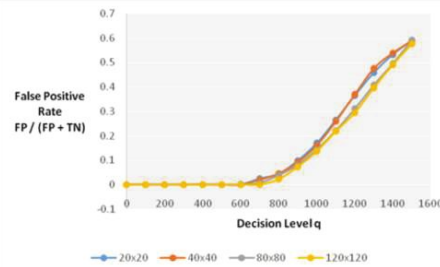
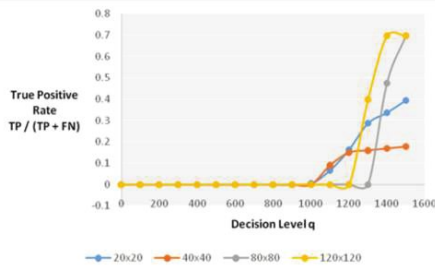
Results: Crawl

- ▼ SWIR-31148, frame 269



Results: Walk

▼ SWIR-31148, frame 269



7/31/2009

13

Conclusions

▼ Summary

- Detection performance also depends on target signature selection, which may be scale/pose variant

▼ Acknowledgements

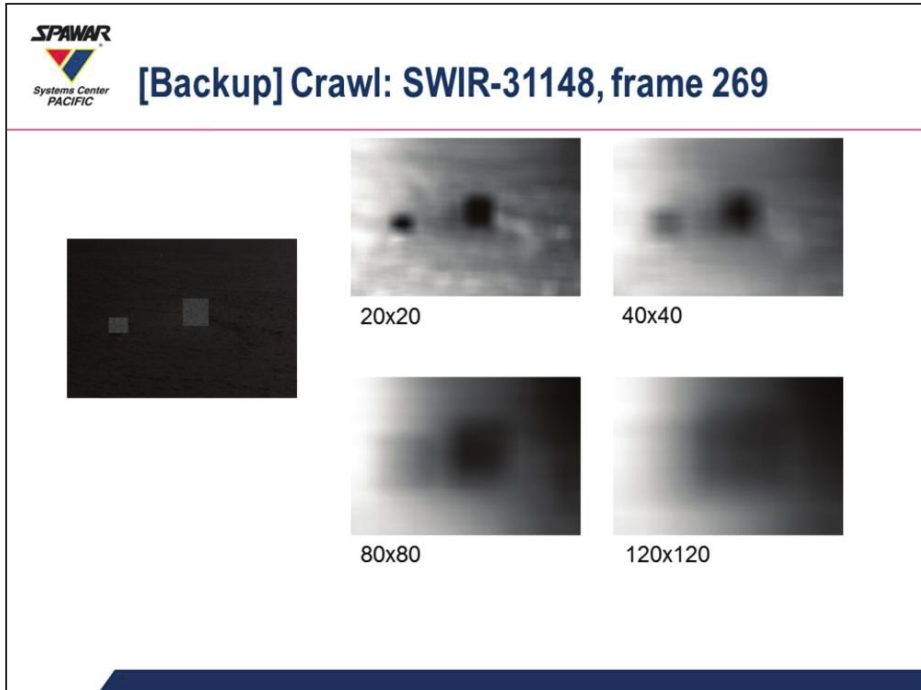
- US Office of the Secretary of Defense (OSD), Coalition Warfare Program (CWP)
- Republic of Singapore, Ministry of Defence (MINDEF), Defence Research and Technology Office (DRTech)

▼ References

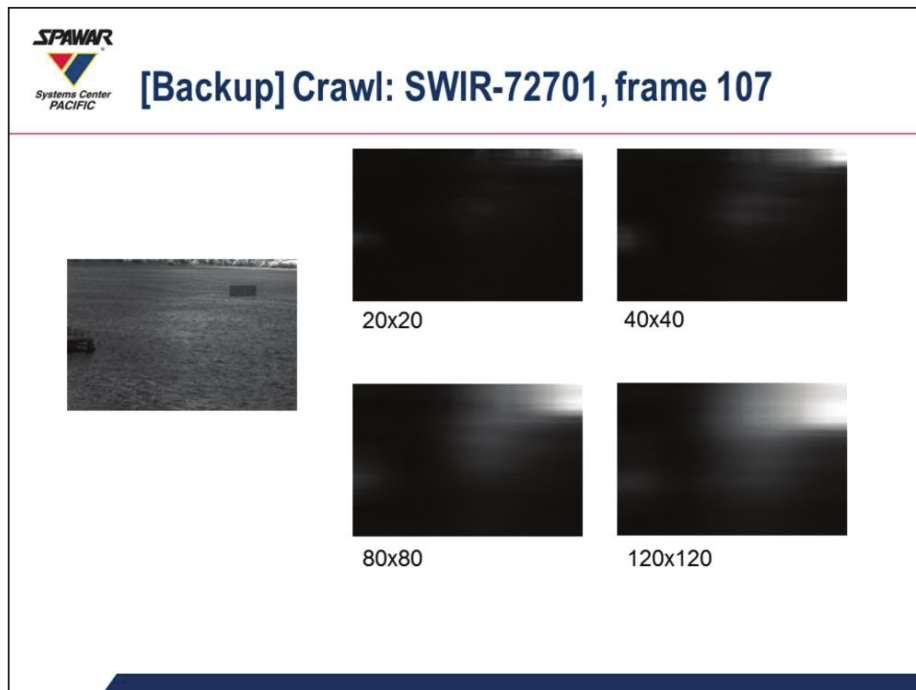
1. Stotts, L., and Hoff, L., "Statistical detection of resolved targets in background clutter using optical/infrared imagery," Applied Optics, July 2014.
2. Vondrick, C., Ramanan, D., and Patterson, D. "Efficiently scaling up video annotation with crowdsourced marketplaces," European Conference on Computer Vision, Crete, Greece, September 2010.

7/31/2009

14

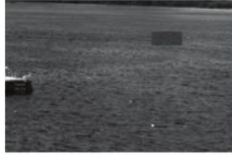


Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.



Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.

[Backup] Crawl: SWIR-73402, frame 663



20x20



40x40



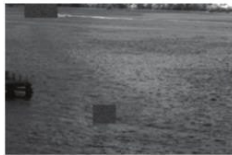
80x80



120x120

Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.

[Backup] Crawl: SWIR-80401, frame 254



20x20



40x40

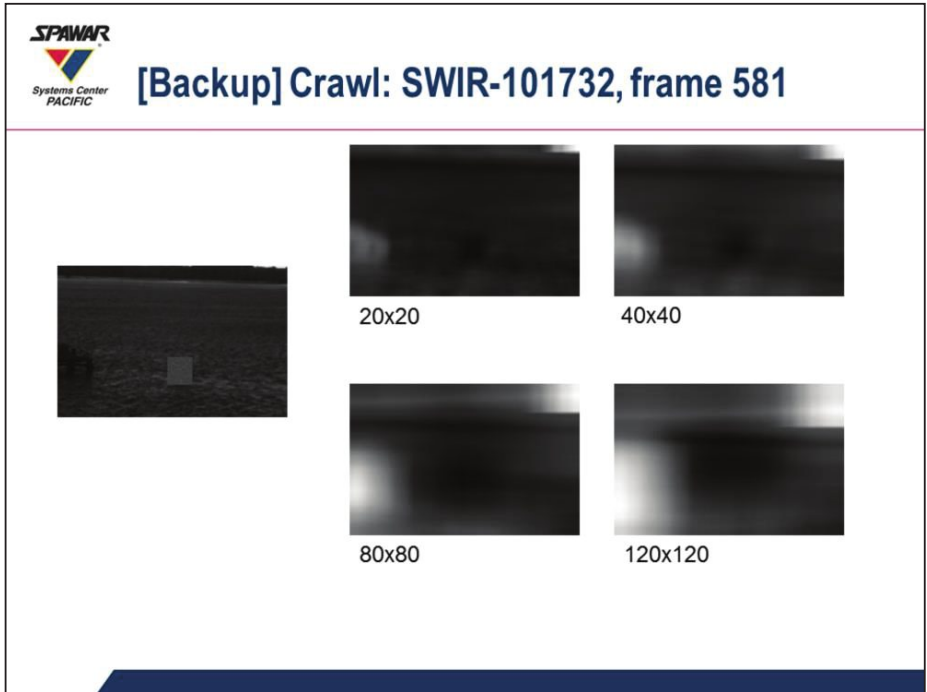


80x80

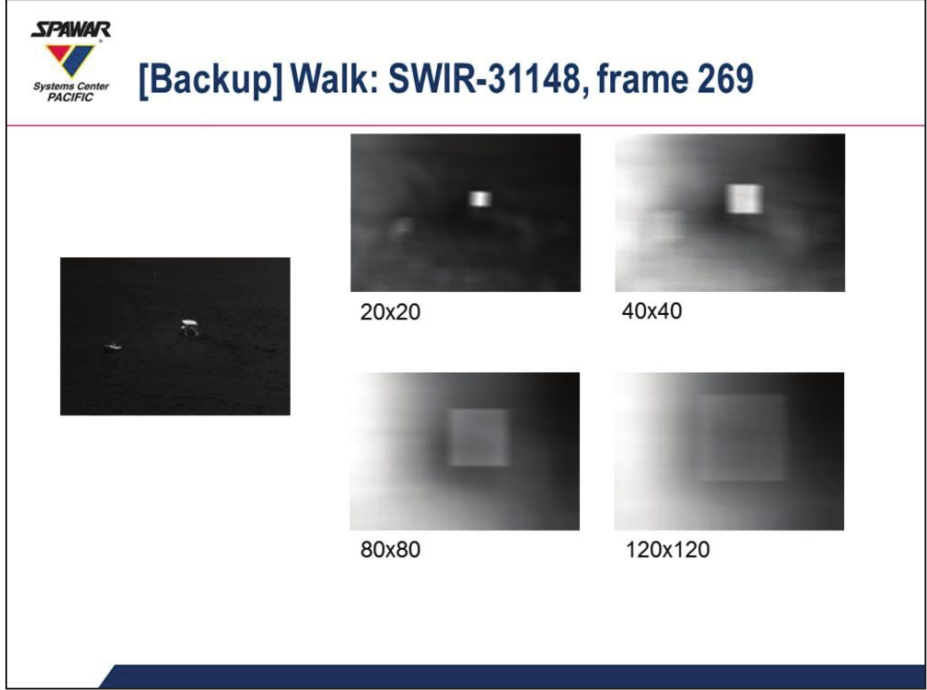


120x120

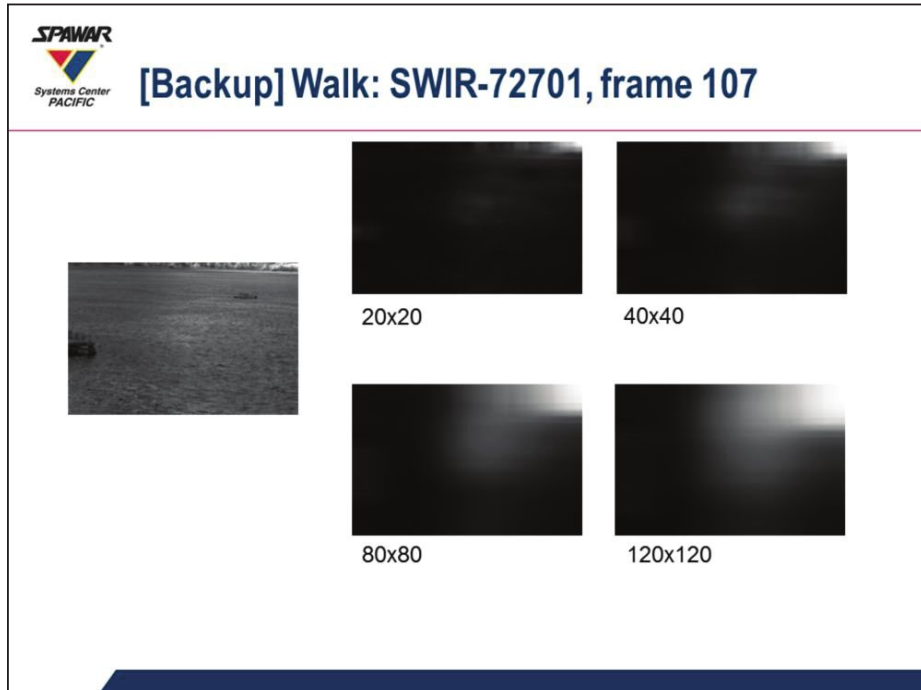
Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.



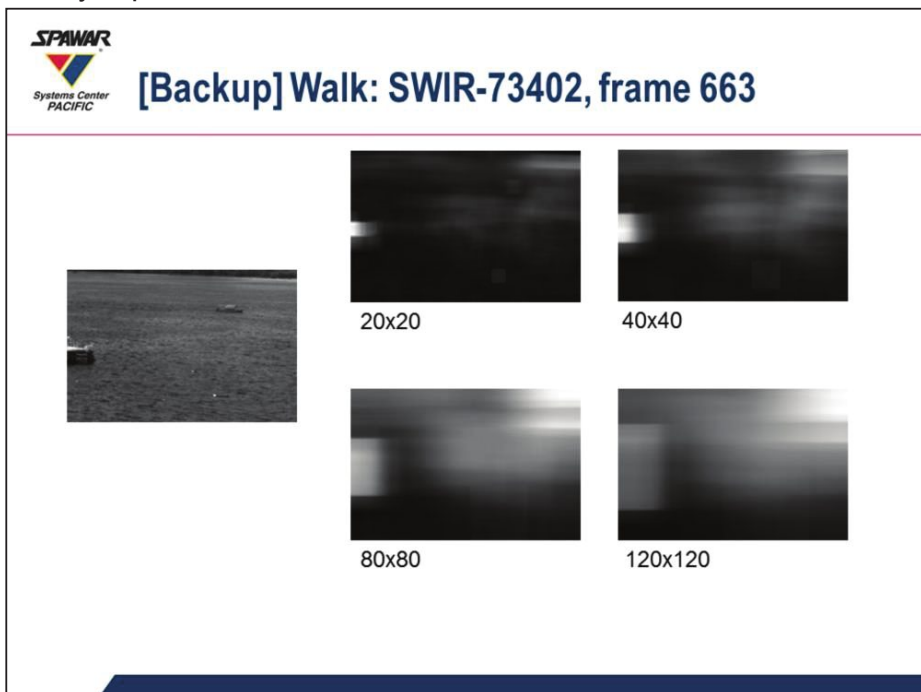
Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.



Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.



Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.



Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.

[Backup] Walk: SWIR-80401, frame 254



20x20



40x40



80x80



120x120

Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.

[Backup] Walk: SWIR-101732, frame 581



20x20



40x40



80x80



120x120

Test statistic images have been normalized for viewing purposes. The pixel intensity values represent the relative confidence that the pixel contains anomalies (targets). Darker values represent relatively higher confidence that an anomaly is present.