NATIONAL RESEARCH COUNCIL

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ROBUST METHODS FOR THE ANALYSIS OF IMAGES AND VIDEOS FOR FISHERIES STOCK ASSESSMENT

A National Research Council Workshop
Sponsored by NOAA Fisheries

BOARD ON MATHEMATICAL SCIENCES AND THEIR APPLICATIONS
COMMITTEE ON APPLIED AND THEORETICAL STATISTICS

MAY 16-17, 2014

2101 CONSTITUTION AVE NW
WASHINGTON, DC
NAS LECTURE ROOM

Meeting objectives

1. Examine the frontiers in methodology for the use of image, video, and possibly other sensor data relating to the following tasks:
    - Automatic counting or characterization of fish as they pass through a trawl against a semi-static background;
    - Interpreting video (e.g., identifying the species, counting individuals, characterizing their size distribution) from a stationary camera that views fish against the bottom of a body of water;
    - Automatic interpretation (counting and characterizing) of individual snapshot images taken from a remotely operated moving camera; and
    - Automatic counting and characterization of fish in videos against a natural background.

2. Involve participants from diverse fields to address the following topics:
    - Identify promising directions for advancing NMFS's analytical capabilities for the tasks listed above, including opportunities to leverage capabilities from other fields; and
    - Share perspectives about the most efficient path toward more automation of fisheries stock assessments, identifying goals that might be achieved through 3-5 years of modest R&D investment and goals that should be considered longer term.

Day 1: Friday, May 16th

7:30 am Coffee and light breakfast available

8:00 am	**Welcome, Introductions, and Overview**

Welcome, framing of the meeting and agenda overview

Opening remarks and meeting overview
Prof. Rama Chellappa, University of Maryland, College Park, Workshop Planning Committee Chair
Dr. Ned Cyr, NOAA Fisheries
(http://vimeo.com/album/2908324/video/97535293)
Dr. Richard Merrick, NOAA Fisheries
(http://vimeo.com/album/2908324/video/97535294)

8:15 am	**Setting the Stage**

This session will discuss current approaches used to count fish and some potential options that may be used in the future.

Session chairs: Dr. Rick Methot, NOAA Science Advisor for Stock Assessment and Prof. Rama Chellappa

- **Session format**
  - **Overview of Types of Data Used in Fisheries Stock Assessment**
    Dr. Allan Hicks, NOAA Fisheries
    (http://vimeo.com/album/2908324/video/97535296)
  - **Overview of Sampling in Space and Time**
    Prof. Steven Thompson, Simon Fraser University
    (http://vimeo.com/album/2908324/video/97535297)
  - **Overview of NOAA Fisheries' Strategic Initiative on Automated Image Analysis**
    Dr. Benjamin Richards, chair of the Strategic Initiative, NOAA Fisheries
    (http://vimeo.com/album/2908324/video/97535298)
  - **Overview of Computer Vision**
    Prof. Ruzena Bajcsy, University of California, Berkeley
    (http://vimeo.com/album/2908324/video/97540648)

  Q&A and Open Discussion
  (http://vimeo.com/album/2908324/video/97540651)

- **Background papers for session**:
  - Beijbom, O., P.J. Edmunds, D.I. Kline, B.G. Mitchell, and D. Kriegman. (2012) Automated annotation of coral reef survey images. *Computer Vision and Pattern Recognition (CVPR), 2012 IEEE Conference on*:1170–1177

- Cadima, E.L. 2003. Fish Stock Assessment Manual. FAO Fish Tech Pap No 393:161.
- Cappo, M., E.S. Harvey, M. Shortis. 2006. Counting and measuring fish with baited video techniques - an overview. *Australian Society for Fish Biology Workshop Proceedings* 101–114
- Chen, H., S. Huang, H.L. Bart. 2006. Taxonomy in Fish Species Complexes: A Role for Multimedia Information. *Multimedia Signal Processing*, 2006 IEEE 8th Workshop on:475–479
- Kimura, D.K. and D.A. Somerton. 2006. Review of statistical aspects of survey sampling for marine fisheries. *Reviews in Fisheries Science*, 14:245–283
- Mace, P.M., N.W. Bartoo, A.B. Hollowed, P. Kleiber, and others. 2001. Marine Fisheries Stock Assessment Improvement Plan. Report of the National Marine Fisheries Service National Task Force for Improving Fish Stock Assessments. NOAA Technical Memorandum NMFS-F/SPO-56
- Mallet, D. and D. Pelletier. 2014. Underwater video techniques for observing coastal marine biodiversity: A review of sixty years of publications (1952-2012). *Fisheries Research*, 154:44-62.
- NOAA Fisheries. 2012. Stock Assessment: The Core of Fisheries Science.
- Sale, P.F. 1997. Visual census of fishes: How well do we see what is there? Proceedings of the 8th International Coral Reef Symposium 2:1435–1440.
- Shortis, M.R., M. Ravanbakskh, F. Shaifat, E.S. Harvey, and others. 2013. A review of techniques for the identification and measurement of fish in underwater stereo-video image sequences. 8791:87910G–87910G.
- Spampinato, C., Y.-H.Chen-Burger, G. Nadarajan, R.B. Fisher. Detecting, tracking and counting fish in low quality unconstrained underwater videos.
- Spampinato, C., D. Giordano, R. Di Salvo, Y.-H. Chen-Burger, R.B. Fisher, G. Nadarajan. 2010. Automatic fish classification for underwater species behavior understanding. *Proceedings of the first ACM international workshop on Analysis and retrieval of tracked events and motion in imagery streams* 45–50.
- Sparre, P, Venema, SC (1992) Introduction to tropical fish stock assessment. 376.
- Western Pacific Regional Fishery Management Council (2004) Coral Reef Fish Stock Assessment Workshop. Interim Final Panel Report 29
- Williams, K., C. Rooper, and J. Harms. 2010. Report of the national marine fisheries service automated image processing workshop. NOAA Tech Memo NMFS-F/SPO-121

- **Session questions:**
  - What has been done and what are the gaps?
  - What areas of intersections exist between computer vision and fisheries stock assessment, and where can cross-fertilization occur?
  - What is the role of the domain expert? How does each domain affect the other?

- What are the trade-offs and relative benefits between computer vision methods versus crowd sourcing efforts?
- What existing computing tools (e.g., trackers, particle filterers, feature leaning, etc.) can be applied to fisheries?
- What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?

10:10 am	**Break**

10:25 am	**Multi-Modal Sensing**

This session will provide an overview of multi-modal sensing and discuss some of the key challenges associated with various types of sensor data (image, video, LIDAR, hyperspectral, and stereo with motion) of relevance to fisheries stock assessments.

Session chair: Prof. Nicholas Makris, Massachusetts Institute of Technology

- **Session format**
  - **Fisheries Perspective of Multi-Modal Sensing**
    Dr. Dvora Hart, Northeast Fisheries Science Center
    (http://vimeo.com/album/2908324/video/97540652)
  - **Synergistic Acoustic and Optic Observation and Estimation**
    Dr. Jules Jaffe, University of California, San Diego
    (http://vimeo.com/album/2908324/video/97540653)
  - **Low Frequency Acoustic Imaging for Large Area Surveys**
    Prof. Nicholas Makris, Massachusetts Institute of Technology
    (http://vimeo.com/album/2908324/video/97540654)
  - **Seafloor Laser Imaging Techniques**
    Prof. Fraser Dalgleish, Florida Atlantic University
    (http://vimeo.com/album/2908324/video/97543712)

  Q&A and Open Discussion
  (http://vimeo.com/album/2908324/video/97543713)

- **Background papers for session**:
  - Atrey, P. K., Hossain, M. A., El Saddik, A., & Kankanhalli, M. S. (2010). Multimodal fusion for multimedia analysis: a survey. *Multimedia systems*, 16(6):345-379.

- **Session questions:**
  - What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?

- How do you measure the statistical significance and variance for fisheries?
- What is the precision in the abundance and size estimate that is required for stock assessors?
- What are the methods to improve desired accuracy and species identification?
- What is the relevant range of sizes of species required by stock assessors?
- What are the best types of fisheries data available for existing computer vision techniques? How can optical sensor data be augmented with other sensor modalities that are more compatible with computer vision methods?
- What additional data sources would improve the accuracy of computer vision annotation of fish?
- Are there adequate data fusion and visualization tools available to analyze multi-modal data?

12:15 pm	**Lunch Keynote**

Prof. Demetri Terzopoulos, University of California, Los Angeles to speak on artificial life simulations and the cross over with fisheries modeling (http://vimeo.com/album/2908324/video/97543719)

1:15 pm	**Image Processing and Detection**

This session will include presentations discussing issues such as imaging platforms, color and illumination correction, segmentation, recognition, and species detection.

Session chair: Prof. Chuck Stewart, Rensselaer Polytechnic Institute

- **Session format**
  - **Introduction to Fisheries Data Pre-Processing**
    Dr. Clay Kunz, Google
    (http://vimeo.com/album/2908324/video/97543721)
  - **Underwater Robotic Platforms and Imaging**
    Dr. Hanumant Singh, Woods Hole Oceanographic Institution
    (http://vimeo.com/album/2908324/video/97543722)
  - **Underwater Tele-Immersion: Potential and Challenges**
    Prof. Ruzena Bajcsy, University of California, Berkeley
    (http://vimeo.com/album/2908324/video/97544361)
  - **Underwater Imaging and Detection**
    Prof. Chuck Stewart, Rensselaer Polytechnic Institute
    (http://vimeo.com/album/2908324/video/97544362)

    Q&A and Open Discussion
    (http://vimeo.com/album/2908324/video/97544363)

- **Background papers for session**:

- Dawkins, M.D., C.V.Stewart, S.Gallager, and A.York. 2013. Automatic Scallop Detection in Benthic Environments. IEEE Workshop on Applications of Computer Vision, Jan 2013.
- Kaeli, J.W. and H. Singh. Illumination and Attenuation Correction Techniques for Underwater Robotic Optical Imaging Platforms.
- Tolimieri, N., M. E. Clarke, H. Singh, and C. Goldfinger. Evaluating the SeaBED AUV for Monitoring Groundfish in Untrawlable Habitat. Marine Habitat Mapping Technology for Alaska. J.R. Reynolds and H.G. Greene (eds.). doi:10.4027/mhmta.2008.09. Pp. 129-141.
- Treibitz, T., Y. Y. Schechner, C. Kunz, and H. Singh. 2012. Flat Refractive Geometry. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 34(1):51-65.

- **Session questions:**
  - How can a research community combining computer vision and oceanography be built and sustained?
  - What are some of the differences with working underwater and with fish, in particular?
  - What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?
  - How can NMFS best leverage the rapidly-growing, diverse set of approaches for detection, segmentation, and classification in the computer vision literate?
  - What are the challenges to adapting methods from computer vision to fisheries assessment? Are there different underlying assumptions? Do new problems arise?
  - How should sensors be chosen for a given application and given data fusion methods?
  - What are the requirements on spatio-temporal resolution, illumination, blur removal, SNR improvement?
  - How can shape and motion-based detection be used together?
  - What are the novel ways of detecting and segmenting targets using computer vision (e.g., would DPM be effective for fish)?

3:15 pm	**Break**

3:30 pm	**Multi-Object Tracking**

This session will include presentations from domain areas distinct from traditional areas of fisheries research, specifically with respect to extracting species-specific characteristics, minimizing double counting, and species-specific parameterization. The goal is to draw similarities to work being done in other fields and examine area where capabilities of these other fields can be leveraged within fisheries.

Session chair: Prof. Mubarak Shah, University of Central Florida

- **Session format**
  - **Multi-Object Multi-View Tracking**
    Prof. Margrit Betke, Boston University
    (http://vimeo.com/album/2908324/video/97544364)
  - **Crowd Tracking and Group Action Recognition**
    Prof. Mubarak Shah, University of Central Florida
    (http://vimeo.com/album/2908324/video/97544365)
  - **Tracking in the Ocean, Vehicles and Fish**
    Dr. Jules Jaffe, University of California, San Diego
    (http://vimeo.com/album/2908324/video/97545689)
  - **Shape and Behavior-Encoded Tracking**
    Prof. Ashok Veeraraghavan, Rice University
    (http://vimeo.com/album/2908324/video/97545690)

  Q&A and Open Discussion
  (http://vimeo.com/album/2908324/video/97545691)

- **Background papers for session**:
  - Schell, C., and S.P. Linder. 2006. Experimental evaluation of tracking algorithms used for the determination of fish behavioral statistics. *Oceanic Engineering, IEEE*, 31(3): 672-684.
  - Schell, C., S.P. Linder, and J. R. Zeider. 2004. Tracking highly maneuverable targets with unknown behavior. *Proceedings of the IEEE,* 92(3): 558-574.
  - Yilmaz, A., O. Javed, and M. Shah. 2006. Object Tracking: A Survey. *ACM Computing Surveys*, 38(4).

- **Session questions:**
  - What are the techniques from computer vision that can be applied to the identification of fish species by shape, motion and behavior? What other characteristics can be used to classify fish/inverts that have not yet been considered?
  - What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?
  - Are there novel methods to ensure accuracy of image- and video-based estimates (e.g., eliminate double counts, reduce misclassification, estimate confidence in results, etc.)?
  - How can tradeoffs between necessary resolution for identification and a wide field-of-view for tracking be balanced?

5:50 pm	**Summary and Preview of Next Day**

http://vimeo.com/album/2908324/video/97545692

6:00 pm	**Adjourn**

Day 2: Saturday, May 17th

8:00 am Coffee and light breakfast available

8:30 am	**Shape and Motion Analysis**

This session will discuss current approaches used to classify fish and identify key parameters such as size, shape, texture, color, and motion.

Session chair: Dr. Hui Cheng, SRI, International

- **Session format**
  - **Overview of How Sizing is Currently Done in Fisheries (by Hand and Optically)**
    Dr. Elizabeth Clarke, NOAA Fisheries
    (http://vimeo.com/album/2908324/video/97860811)
  - **Shape Analysis**
    Prof. Anuj Srivastava, Florida State University
    (http://vimeo.com/album/2908324/video/97860807)
  - **Behavioral Analysis and Action Recognition**
    Dr. Anthony Hoogs, KitWare
    (http://vimeo.com/album/2908324/video/97860808)
  - **Multi-Cue Entity Detection and Tracking**
    Dr. Hui Cheng, SRI, International
  - **Geodesic Positioning Systems for Biological Coordinate Systems and High Throughput Informatics**
    Prof. Michael Miller, Johns Hopkins University
    (http://vimeo.com/album/2908324/video/97860810)

  Q&A and Open Discussion
  (http://vimeo.com/album/2908324/video/97860812)

- **Background papers for session**:

  Shape and Pattern Theory
  - Miller, M., A.V. Faria, K. Oishi, and S. Mori. 2013. High-throughput neuro-imaging informatics. *Frontiers in Neuroinformatics*. 7:31.
  - Miller, M.I., L. Younes, A Trouvé. 2014. Diffeomorphometry and geodesic positioning systems for human anatomy. *Technology*, 2(1):36.

  Extraction and shape analysis of 2D contours/boundaries of fishes in images
  - Dryden, I., and K. Mardia. 1998. Statistical Shape Analysis. Wiley.
  - Srivastava, A., E. Klassen, S. Joshi, and I. Jermyn. 2011. Shape Analysis of Elastic Curves in Euclidean Spaces. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 33(7):1415-1428.
  - Kurtek, S., A. Srivastava, E. Klassen, and Z. Ding. 2012. Statistical Modeling of Curves Using Shapes and Related Features. *Journal of American Statistical Association*. 107(499):1152-1165.

  Shape Matching

- Hsiao, E., and M. Hebert. 2013. Gradient networks: Explicit shape matching without extracting edges. AAAI.
- Gu, S., Y. Zheng, and C. Tomasi. 2012. Twisted Window Search for Efficient Shape Localization. *IEEE Conference on Computer Vision and Pattern Recognition*, pages 167-173.
- Zhu, Q., L. Wang, Y. Wu, and J. Shi. 2008. Contour context selection for object detection: A set-to-set contour matching approach. *ECCV08*.
- Thayananthan, A., B. Stenger, P.H.S. Torr, R. Cipolla. 2003. Shape context and chamfer matching in cluttered scenes. *Computer Vision and Pattern Recognition Proceedings*.
- Belongie S., J. Malik, J. Puzicha. 2002. Shape Matching and Object Recognition Using Shape Contexts. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 24(4):509-522.

Motion:

- Ochs, P., J. Malik, and T. Brox. 2014. Segmentation of moving objects by long term video analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*.
- Ricco, S., and C. Tomasi. 2012. Dense Lagrangian Motion Estimation with Occlusions. *IEEE Conference on Computer Vision and Pattern Recognition*, pages 1800-1807.
- Sundaram, N., T. Brox, and K. Keutzer. 2010. Dense point trajectories by GPU-accelerated large displacement optical flow. *European Conference on Computer Vision (ECCV),* Springer, LNCS.

- **Session questions:**
  - What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?
  - What are the strengths and weaknesses of current techniques of shape and motion analysis for fisheries stock assessment? What are the requirements?
  - What are the domain specific challenges for shape and motion estimation (e.g., water movement generated motion, independent fish motion, low signal-to-noise ratio, low contract, partial occlusion, etc.)?
  - Is there a set of domain specific shape and motion primitives and statistical models in fisheries stock assessment? Is there a set of primitives and statistical models for the background and for the fishes of interest?
  - How can shape and motion features from multi-modal sensing be exploited for fisheries applications?
  - How can shape, motion, multi-modal, and other information be fused to improve the effectiveness of shape and motion analysis?
  - Are there methodologies or lessons learned from non-aquatic shape and motion analysis that are applicable to fish?

10:30 am	**Break**

10:45 pm	**Identification and Classification**

This session will discuss current approaches for identification and classification with potential applications to fish.

Session chair: Prof. David Jacobs, University of Maryland, College Park

- **Session format**
  - **Automatic Analysis of Benthic Reef Images**
    Prof. David Kriegman, University of California, San Diego
    (http://vimeo.com/album/2908324/video/97866139)
  - **Classifying Leaves Using Shape**
    Prof. David Jacobs, University of Maryland, College Park
    (http://vimeo.com/album/2908324/video/97866140)
  - **Classifying Birds**
    Prof. Serge Belongie, Cornell Tech
    (http://vimeo.com/album/2908324/video/97866141)
  - **Tracking Vehicles in Large-Scale Aerial Video of Urban Areas**
    Dr. Gunasekaran S. Seetharaman, Air Force Research Laboratory
    (http://vimeo.com/album/2908324/video/97866142)

  Q&A and Open Discussion
  (http://vimeo.com/album/2908324/video/97866143)

- **Background papers for session**:
  - Beijbom, O., P.J. Edmunds, D.I. Kline, G.B. Mitchell, and D. Kriegman. 2012. Automated Annotation of Coral Reef Survey Images. *IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Providence, Rhode Island, June 2012*.
  - Branson, S., G. Horn, C. Wah, P. Perona, S. Belongie. 2014. The Ignorant Led by the Blind: A Hybrid Human–Machine Vision System for Fine-Grained Categorization. *International Journal of Computer Vision (IJCV), February, 2014*.
  - Kumar, N. P.N. Belhumeur, A. Biswas, D. Jacobs, W.J. Kress, I. Lopez, J.V.B. Soares. 2012. Leafsnap: A Computer Vision System for Automatic Plant Species Identification. *European Conference in Computer Vision (ECCV)*.
  - Wah, C., G. Horn, S. Branson, S. Maji, P. Perona, S. Belongie. 2014. Similarity Comparisons for Interactive Fine-Grained Categorization. Computer Vision and Pattern Recognition (CVPR), Columbus, OH, June, 2014.

- **Session questions:**
  - What are the difficulties of automating the sizing of fish from images?
  - To what extent is the experience with land animals applicable to fish?
  - What are the differences in ways that humans and computers optically classify objects?
  - What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?

- Are there novel methods to ensure accuracy of image- and video-based estimates (e.g., eliminate double counts, reduce misclassification, estimate confidence in results, etc.)?
- What are the pros and cons of supervised, unsupervised, and semi-supervised learning algorithms? Are there methods that are more or less suited to fisheries applications?

12:30 pm	**Lunch Keynote**

Dr. Concetto Spampinato, Università di Catania (Italy) to talk about Fish4Knowledge. (http://vimeo.com/album/2908324/video/97868364)

1:30 pm	**Conclusions and Strategies Going Forward**

Panel members will be charged with highlighting very specific next steps laid out in the course of workshop presentations and discussions and/or suggesting some of their own.
(http://vimeo.com/album/2908324/video/97868365)

- **Session format (panel discussion):**
  - Prof. Rama Chellappa, University of Maryland, College Park, Workshop Planning Committee Chair
  - Dr. Ned Cyr, NOAA Fisheries (maybe Rick Methot)
  - Dr. Benjamin Richards, NOAA Fisheries, chair of the Strategic Initiative
  - Prof. Nicholas Makris, Massachusetts Institute of Technology
  - Prof. Chuck Stewart, Rensselaer Polytechnic Institute
  - Prof. Mubarak Shah, University of Central Florida
  - Dr. Hui Cheng, SRI, International
  - Prof. David Jacobs, University of Maryland, College Park

- **Session questions:**
  - What are the most efficient paths toward more automation of fisheries stock assessments?
  - What are some key areas of investment that would improve automation of fisheries stock assessment? What should be NOAA Fisheries' priorities for short-, mid-, and long-term investment?

2:30 pm	**Summary and Next Steps**

Comments from the Planning Committee and Sponsor

Prof. Rama Chellappa, University of Maryland, College Park, Workshop Planning Committee Chair

Dr. Ned Cyr, NOAA Fisheries

3:00 pm	**Adjourn**

Planning Committee

Chair

Rama Chellappa, University of Maryland, College Park

Members

Ruzena Bajcsy (NAE, IOM), University of California, Berkeley
Lise Getoor, University of California, Santa Cruz
Alfred Hero, III, University of Michigan
Anthony Hoogs, Kitware, Inc.
David Kriegman, University of California, San Diego
Richard Leahy, University of Southern California
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