# Improved 3-D video analysis methods

## with applications to wild juvenile Chinook salmon foraging behavior

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# Introduction

## 3-D video analysis in fish ecology

We present an affordable system of off-the-shelf hardware, free software, and a simple workflow to take 3-D measurements in the field or lab. This technology enables the investigation of previously intractable questions, such as intra-school competition or fine-scale habitat selection behavior.

In 1996, two of us (Hughes and Kelly) first used multiple-view underwater video measurement to quantify fish behavior in a natural environment. However, widespread use of such techniques has been limited for two reasons we now address:

- A lack of easy-to-use 3-D video analysis software.
- Impractical restrictions imposed by the geometrical methods of early video measurement techniques.

## Why the new method?

The simplicity of digital video capture has accelerated the adoption of video as a measurement tool, but the lack of standard protocols and software has led different researchers to develop a broad medley of limited, often one-time-use methods.

Many such methods only measure in 2-D. Of the 3-D methods, some can only measure within the volume of their calibration object. Others measure only lengths rather than positions and require a perfect side view of the target. Others require cameras to be parallel, or of a special internal design.

Our method removes these limitations. It is more accurate, more versatile, easier to learn, and faster to use.

# Objectives

## Ecological

Our primary objective was to measure the effects of intra-school competition on the foraging behavior of wild juvenile Chinook salmon during their first summer in the Chena River, central Alaska. To accomplish this, we set and met three performance standards for our measurement technology:

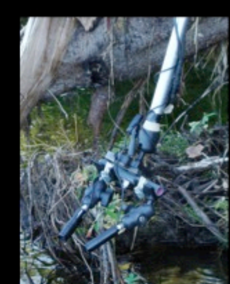
## Technological

- Camera/calibration system must be affordable and tough enough to survive rattling around in boats and filming fish in tight places in logjams.
- Analysis software must allow users to rapidly digitize, organize, and visualize thousands of 3-D points.
- Mathematical methods must offer ~1mm 3-D measurement precision, provide error estimates, correct common distortion/misalignment problems, and work with flexible camera configurations.

# Methods Developed

## Camera and calibration hardware

We constructed a mobile, wide-angle, high-definition camera system weighing ~11 kg (right), and a mini system < 2 kg (left).

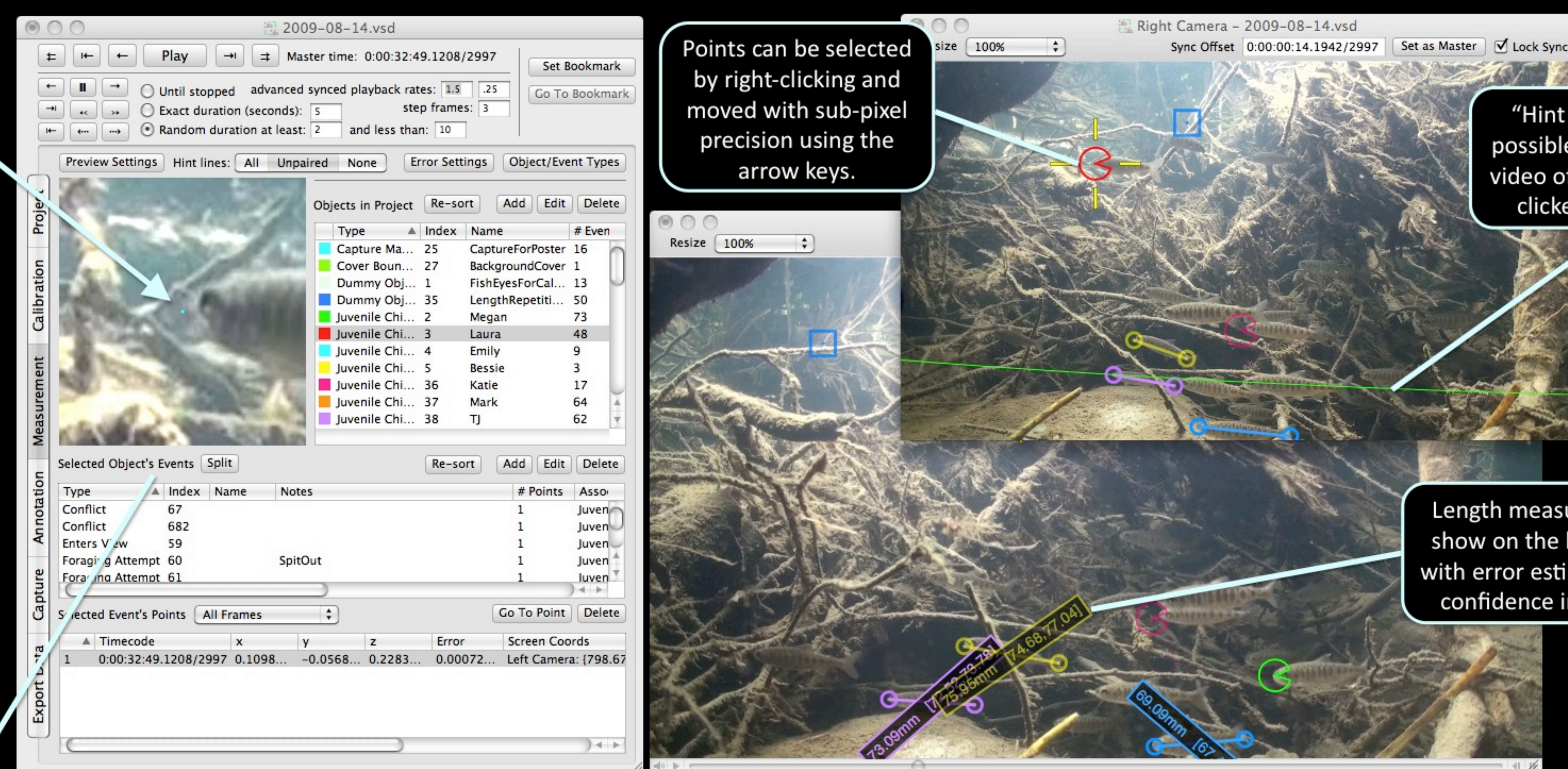


Calibration requires an object with many straight edges (e.g., checkerboard) to calculate radial distortion, and a 3-D quadrat (below under "Mathematics") to define the 3-D coordinate system. Our quadrat is a clear Lexan polycarbonate box with a grid of silicone dots drilled into two opposing sides.

## 3-D analysis software: VidSync

We created VidSync, a user-friendly application for Mac OS X 10.6+, to synchronize, play, and analyze videos. It performs 3-D calculations and error estimation, organizes data in a customizable object hierarchy, and exports results for spreadsheets or the companion Mathematica program VidSync Visualizer. It supports any number (≥2) of cameras in any orientation.

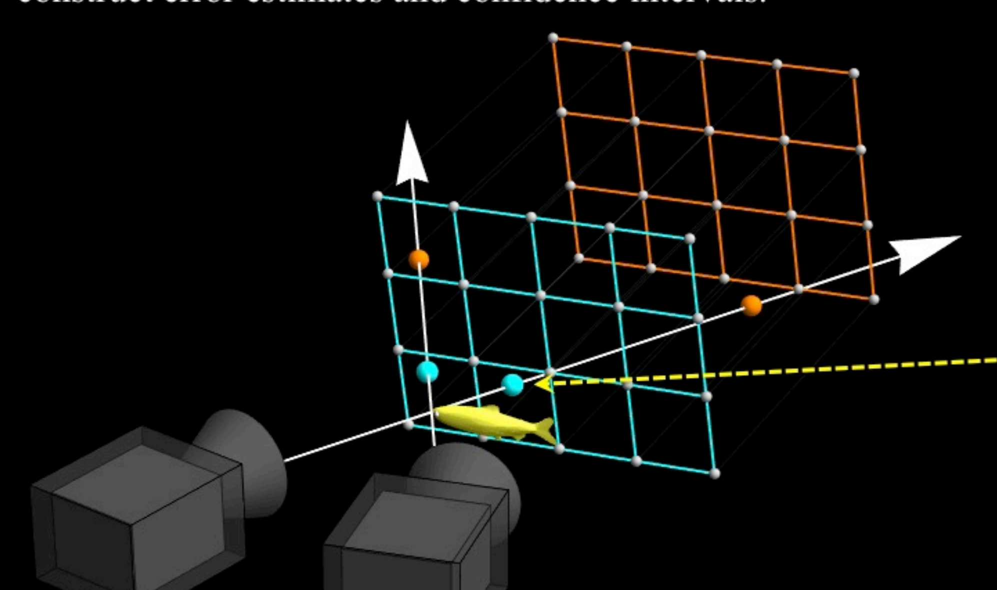
The software, demonstration data, and open source code (in the Objective-C language) can be downloaded for free from **http://vidsync.sourceforge.net**.



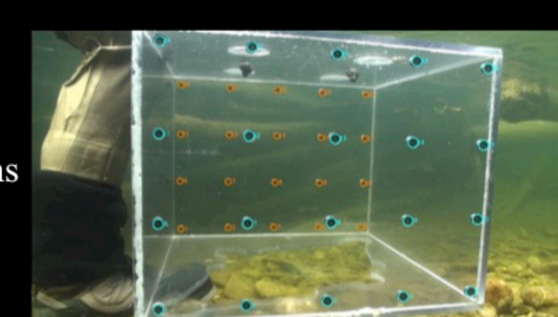

***The VidSync software****. The main window (left) holds the synchronized playback, calibration, export, and measurement controls.*

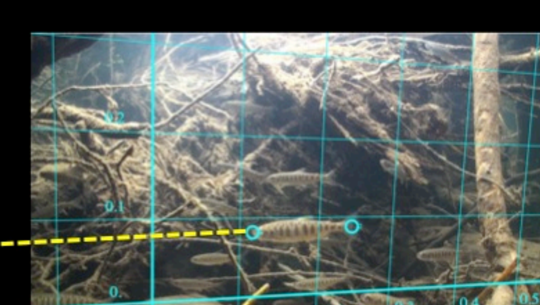
## Mathematics of 3-D measurement in VidSync

VidSync measures 3-D points by calculating the line-of-sight from each camera through the feature being measured (e.g., fish's head). These lines nearly intersect at the feature's 3-D position, and their slight separation is used to construct error estimates and confidence intervals.



Lines-of-sight are calculated by least-squares fitting linear projective transformations to the point grids (right) on each surface of the calibration quadrat.





The transformation allows points to be located on a persistent grid (left), which is mapped into 3-D using known quadrat dimensions.

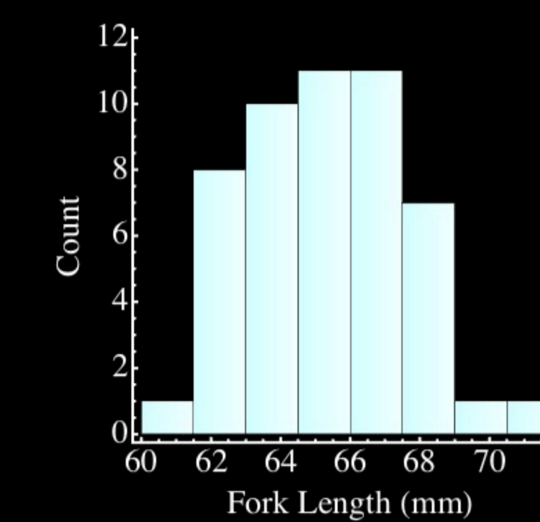
A similar projective transformation can compensate for accidental misalignment of the cameras. VidSync also allows users to compensate for radial (barrel and pincushion) distortion, accounting for both its magnitude and its center.

# Results

## Workflow, from field to finish

1. Videotape flashing LED light (for synchronization).
2. Videotape checkerboard underwater (for radial distortion).
3. Videotape calibration quadrat underwater.
4. Videotape fish.
5. Import videos onto computer.
6. Synchronize videos from different cameras.
7. Click on quadrat/checkerboard dots to establish calibration.
8. Play through the video, measuring and organizing points.
9. Click one button to export all measurements to a spreadsheet.

## Precision

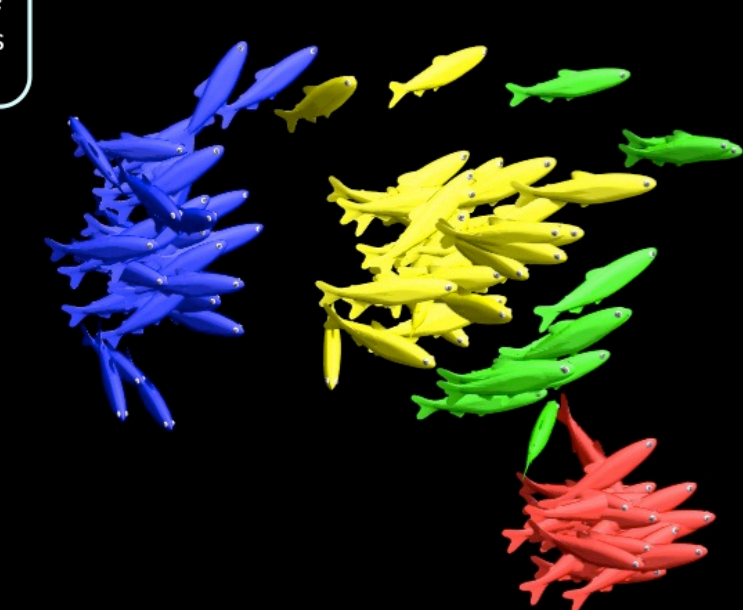



***Repeated measurements****. Histogram shows 50 length measurements of 1 fish in different positions. Variance reflects errors due to motion blurring, body bending, position ambiguity caused by camouflage/lighting, and similar minor effects.*

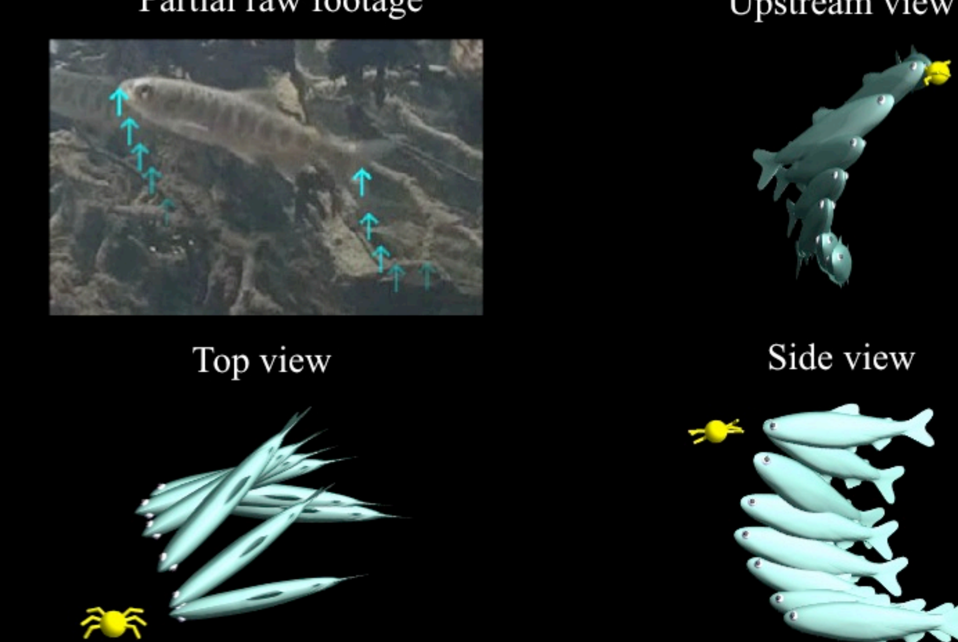
# Sample Applications

See **http://www.chenakings.org** for related videos.

## Feeding territories

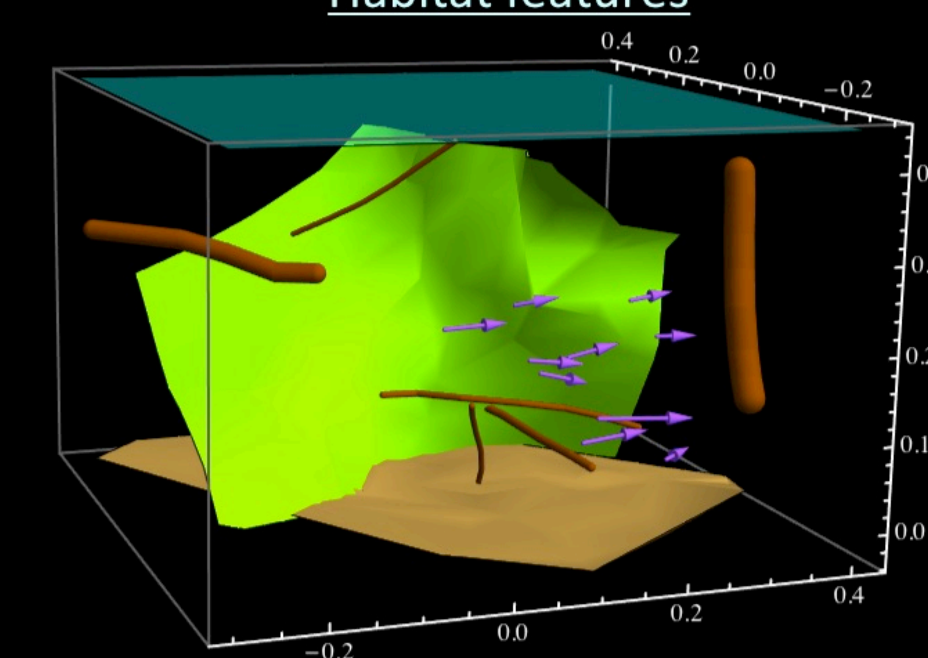


## Prey capture maneuver




***Feeding territories (above)****. Each color represents a different Chinook salmon, and copies represent each prey capture attempt over a 10-min period. Viewing these in 3-D, combined over time, reveals territoriality not apparent from 2-D footage.*

## Habitat features



***Habitat features (right)****. Habitat features in a ~0.5-m cubic area in front of both cameras, including river surface (blue plane, top), river bottom (beige), prominent logs (brown), boundary of dense cover (green surface), and velocity vectors (purple) calculated by tracking naturally drifting particles.*

## Utility

- Studies previously restricted to the lab by the need for precise 3-D measurements can be performed in the field.
- Previous studies involving 3-D measurement were often limited to tiny sample sizes (4-5 fish) by their time-consuming measurement techniques. Our software makes far larger sample sizes practical, improving statistical testability of 3-D results.
- We can measure *any* visible attribute of a fish or its environment, including those that are defined over time (territories) or that change when the fish is disturbed (most behaviors). This makes a broad new class of quantitative data available to ecologists.

# Acknowledgments

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