1) Administrative Information

Institution:	Tulane University Biodiversity Research institute
Project Title:	Prototyping a Multi-Camera, Computer Operated Photogrammetric Imaging System for Enhancing Digital Preservation and Public Access to Natural History Specimens
Project Number	MG-45-15-0003-15
Award Amount:	$23,800
Start Date to End Date:	1 August 2015 – 31 July 2016
PD/PIs:	Dr. Henry L. Bart and Nelson Rios

2) Project Summary

Natural history museums serve a critical role documenting and educating the public about biodiversity. However, only a small percentage of specimens housed in natural history museums are ever put on public display. The vast majority of the specimens in natural history museums are stored in cabinets or on shelves in warehouses accessible only to visiting scientists. Scientists use the specimens primarily for taxonomic research - the science of describing, naming and classifying species and higher groups of organisms. Taxonomists take special interest in examining particular kinds of specimens, called *name-bearing types*, when evaluating whether or not a species they are describing falls within the scope of an already described species. Because of their name-bearing status, type specimens are regarded as the most important specimens housed in natural history museums and herbaria. Type specimens of the oldest described species are among the oldest specimens housed in natural history collections. These specimens are also among the most fragile and delicate specimens housed in collections because of their age and frequent handling by taxonomists. Many collections have policies that restrict shipment of type specimens through the mail, because of fears that the specimens will be lost or damaged. The only way to examine these specimens is by visiting the collections.

Technological advancements over the past two decades have made information about types and other specimens housed in natural history collections available online in digital form, primarily for research purposes. In the past few years more attention has been placed on digital imaging of specimens, in effect bringing the specimens out of their cabinets and increasingly into public view globally via the World Wide Web. Because of their importance to taxonomic study, the specimens with the highest priority for imaging are type specimens. Producing high-quality, study-worthy, digital analogs of type specimens has the potential to serve taxonomy long into the future, especially in cases where the original type specimens are lost or rendered useless due to old age or excessive handling.

In this project, we proposed to prototype a multi-camera, computer-operated photogrammetric imaging system (named COPIS) for photogrammetric 3-D reconstruction of preserved fish specimens. The primary function of the device is to produce a large number of overlapping images from multiple viewpoints around a specimen for photogrammetric 3-D reconstruction; however, the system can also be used to capture single-viewpoint images or multiple images at varying focal depths for use in focus stacking. The multi-camera version of COPIS will comprise a custom-built, photographic light box equipped with six high-resolution DSLR cameras. It will reduce imaging time - and exposure of specimens to air drying - to 5 minutes per specimen, from 30-45 minutes per specimen, based on our work with a single-camera prototype of COPIS.

3) Process

At the onset of this project, we had already developed a single-camera prototype as a proof-of-concept. This prototype was used as the basis for developing the six-camera system developed with IMLS support. We employed an iterative design process that involved: design, fabricate, evaluate, iterate. Electronics were designed using KiCad, mechanical components were designed using OpenScad and Sketchup. Access to a Rep Rap Mendel 90 3D printer and X-Carve milling machine allowed rapid testing and iteration at reduced cost throughout the project. The X-Carve was primarily used to mill axis end-plates from 1/8th inch aluminum plates. The Mendel 90 was used to print the pan and tilt camera mounts and various minor components. T-Slot Aluminum extrusions from MiSUMi USA were used for framing the system. The T-Slot Extrusion allows for greater flexibility in design since components can be easily repositioned on the T-Slot. The linear motion components were based around a V-Slot system in which V-Wheels ride along the V-Slot. PCBs were fabricated in-house using Dupont, Riston Dry Film Photoresist to transfer a positive of the circuit board layout to an FR-2 copper clad board, which was then exposed under UV light and etched using Ferric Chloride. This process allowed rapid testing and iteration of the electrical components. The firmware was written in C++ and developed using Atmel Studio. An Atmel-ICE Debugger/Programmer was used to transfer the firmware to the electronics. PC client software was written in C# and developed using Microsoft Visual Studio.

4) Project Results

The goal of this project was to design and prototype a modular, multi-camera Computer-Operated, Photogrammetric-Imaging System, called COPIS, consisting of a custom-built photographic light box equipped with robotically maneuvered and controllable cameras (Fig. 1). Specifically, our design was prototyped and tested to accommodate 6 DSLR cameras, but the modular nature of the system should support implementations that can scale from 1 to many cameras only constrained by available space, power and z-axis height. Implementations requiring larger Z-axis heights would need additional support to ensure smooth camera movement.

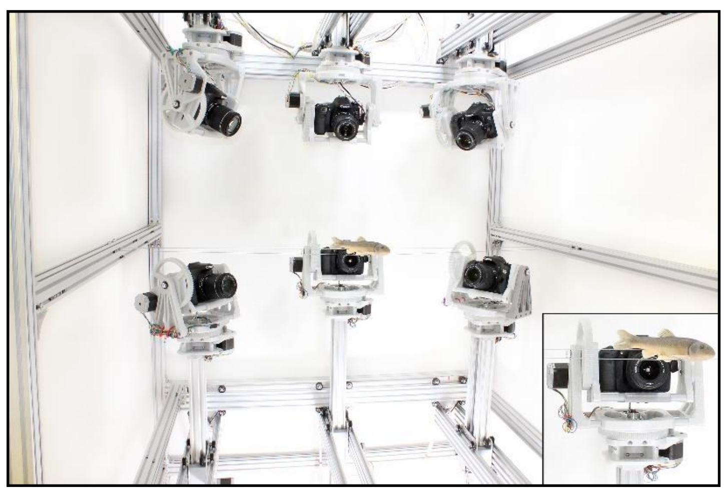

Figure 1. Working prototype of 6 camera COPIS installation showing specimen mounted on two strands of monofilament in specimen staging area.

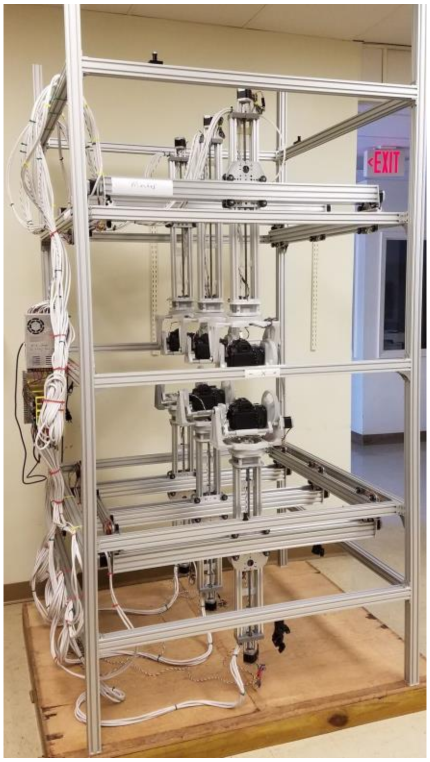

Figure 2. Overview of COPIS framing and mechanics.

The enclosing light box measures 1.29m wide, 1.29m deep and 2.44m high and is divided vertically into three regions. The outer panels are composed of 3mm thick expanded PVC panels. The structural framing elements are made of standard 40x40mm T-slot aluminum extrusions (Fig. 2). The mid region of the box, measuring 1m vertically, serves as the specimen staging area and is lighted with commercial off the shelf photographic LED panels. The upper and lower regions of the framing measure 0.72m in height and each houses the mechanical and electronic components for positioning three cameras around a specimen mounted within the mid region. Specimens are supported two or more on thin rails of monofilament fishing line in the center of the instrument. A benefit of using monofilament is that causes little obstruction of the specimen and is easy to remove in digital post processing of 3d models. The downside to monofilament is that any vibration in the aluminum framing is easily transferred to the rails, so we are evaluating additional rail options including aluminum wire and rigid conduit as well as mounting rail isolation.

Each camera is attached to an integrated, 5-axis, computer-controlled, moveable camera mount and controlled by a custom-built circuit board (Figs. 3 & 4) featuring an Atmel 8-bit AVR ATmega1284p microcontroller with COPIS firmware. Each camera axis is actuated by NEMA 17 stepper motors, Kysan Model number 1124090, rated at 76.4 ounce-inches of torque, 1.8 degrees per full step and driven by an Allegro Microsystems A4988 micro-stepping driver connected to the ATmega1284p. The linear rails for the X,Y and Z-axis are composed of 20x40mm and 20x60mm V-slot aluminum extrusions. Custom-milled .125 inch aluminum plates are used to mount the various X, Y and Z axis components. A belt and pinion system is used for linear actuation of the X and Y-axis. A GT2 timing belt and 18-tooth pulley provide a positional resolution of 11.25um at 1/16th micro-stepping along the X and Y-

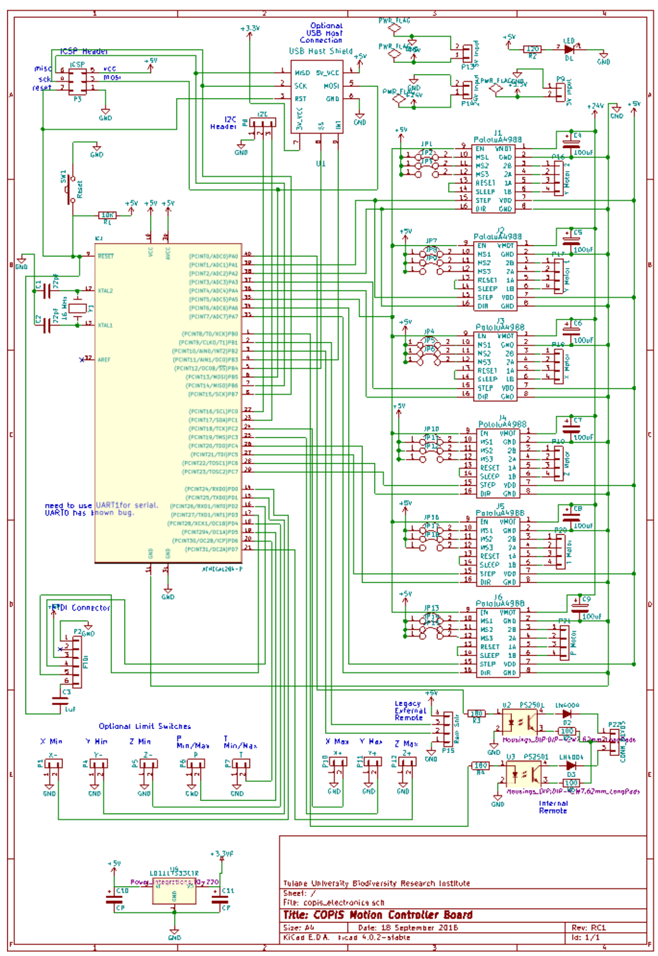

Figure 4. COPIS camera controller circuit.

axis. Linear actuation along the Z-axis is accomplished via an M8x1.25 threaded rod providing 6.25um resolution at full stepping and 0.39um at 1/16th micro-stepping. Enabling micro-stepping on the Z-axis allows the cameras to take traditional focus-stacked images. The Z-axis cable raceway, nut blocks, end caps and gantry stabilizer are 3D-printed from Polylactic Acid (PLA) filament. The pan-and-tilt camera mounts (Fig. 5) are also 3D printed from PLA and feature 9:110 gear reductions, enabling a maximum of .0092 degree positional resolution, along each rotational axis.

COPIS supports a wide array of cameras from varying manufacturers and provides three mechanisms for controlling cameras: 1) for cameras that support the ISO 15740 Picture Transfer Protocol, a Maxim Integrated USB Host Controller (MAX3421E) provides USB connectivity between the camera and the microcontroller enabling advanced USB control of the camera; 2) by engaging remote shutter and/or focus through opto-isolated signals from the microcontroller; and 3) direct computer control of cameras using camera manufacturer software and/or APIs. An FTDI FT232RL USB to UART integrated circuit allows a computer to send preprogrammed instructions to one of the COPIS circuit boards designated as the master. The 5 remaining boards receive their instructions from the Master board. Communication between boards is accomplished via the I-Squared-C (I2C) serial bus.

Figure 5. COPIS pan/tilt camera mount.

At the time of this writing, all COPIS hardware and firmware design have been completed. We have also developed a PC client application for creation of user-programmable camera paths and commands, but continued development of this software is ongoing. We are in the process of compiling the various resources, CAD files, schematics, bill of materials, final cost estimates, suppliers, source code, assembly instructions, demonstration videos etc. for public release on the COPIS (copis.tubri.org) website in the first quarter of 2017.

5) Plans for Future Use of COPIS

A proposal was submitted to the Advancing Digitization of Biodiversity Collections (ADBC) program at the National Science Foundation on 14 October 2016 for a collaborative Thematic Collections Network (TCN) project, involving 11 major fish collections in the U.S. We proposed to proposed to use the COPIS system in the project to produce photogrammetric 3D surface reconstructions of 500,000 specimens representing all species and populations of North America's (N.A.) two most speciose clades of freshwater fishes - Leuciscine cyprinids (a.k.a. N.A. minnows) and Etheostomatine percid fishes (N.A. darters) - from stream hydrologic units across North America (N.A.), inclusive of Canada and Mexico, for future research on morphological diversification of these highly diverse groups of fishes. The participating collections were selected because of their strong regional foci on freshwater fishes in general and N.A. minnows and darters in particular. Minnow specimens will be imaged from rivers across all of North America; darters will be imaged from watersheds east of the continental divide, where these species are native.

Our plan for the project is to purchase and/or manufacture at Tulane University all the necessary components for 10 COPIS instruments during the first six months of the project and ship these to the 10 collaborating institutions. Imaging technicians hired at each of the participating institutions will be trained in using COPIS by the start of the second half of Year 1 and will each work 3.5 years imaging 45,454 specimens per institution to meet the project goal of producing 500,000 3D surfaces representing all populations of all N.A. minnow and darter species. To demonstrate the utility of the 3D surfaces for studies of morphological diversification, 11 undergraduate biology students, recruited from groups underrepresented in the biodiversity collections community, will participate in an 8-week, summer-research experience at the 11 participating institutions (one student per institution), producing 3D surfaces for samples of specimens of 11 North American minnow and darter species, and gathering data for a suite of morphological characters (scale counts and proportional measurements) from both the physical specimens and their 3D digital analogs of the specimens.

The project would be the first application of photogrammetric imaging to fluid-preserved fish specimens, and the first large-scale, collaborative, fish-specimen imaging project. The 3D surfaces produced in the project will serve future research on morphological diversification of N. A.'s two most highly speciose clades of freshwater fishes. It will provide remote (online) access to large numbers of high quality 2-D images and photogrammetric 3-D reconstructions of specimens representing 500 species of freshwater fishes. The research will likely result in descriptions of unrecognized species in unstudied groups of N.A. minnows and darters. Demonstration projects will be conducted to assess the comparability of morphological data gathered from digital analogs of specimens to data gathered from physical specimens.

The project will improve standards and quality of 2-D imaging of fish specimens and will perfect new methods for producing 3-D reconstructions of specimens at greatly reduced time and computational costs than existing approaches involving biodiversity specimens. Methods developed for 3D imagine fish specimens will be useful for imaging other kinds of fluid-preserved specimens (amphibians and reptiles, invertebrates). The project will make digital analogs of fish specimens accessible to much broader audiences, where they can used to educate students about fish diversity, morphology and taxonomy. The large repository of images will serve as a valuable resource for research in computer science, including research evaluating new methods of photogrammetric reconstruction, artificial intelligence and machine learning. Students from groups underrepresented in the biodiversity research collections community will learn about ichthyological research collections, photogrammetry, and gathering morphological data from both physical specimens and 3D digital reconstructions of the specimens. The project will also employ an Outreach Coordinator who will perform a number of outreach activities, including teaching a course on photogrammetric imaging of biodiversity specimens; developing public displays on the project, and disseminating results of the project in a variety of formats and forums.

The IMLS Sparks program was graciously acknowledged in the ADBC proposal for providing the funding to prototype the COPIS system.