Underwater Augmented Reality: Navigation and Identification

Hunter C. Brown
Department of Geography
University of Delaware
Newark, Delaware 19716
hcbrown@udel.edu

Haozhu Wang
Department of Computer
and Information Sciences
University of Delaware
Newark, Delaware 19716
haozwang@UDel.edu

***Abstract*—This paper presents an overview of a novel Underwater Augmented Reality (UAR) system for diver-assistance. The University of Delaware (UD) is pioneering a new diver-mounted platform which serves as the foundation for various application-specific software packages. These software suites, intended for both recreational and commercial divers, will provide divers with heads-up data from a combination of a priori information and real-time sensing. Currently in development are two software packages: 1) a fish identification scheme called Goggle-based Overlay for Fish Identification, Selection, and Highlighting (GOFISH), and 2) a vision-denied navigation enhancement called Diver Augmented Reality and Knowledge for Navigation and Vision (DARKNAV). This paper describes the UD UAR testbed with the GOFISH and DARKNAV projects, and discusses the ongoing scientific and engineering goals.**

I. Introduction

Ever since the first commercial successes with scuba equipment in the 1940s, humans have grown more and more interested in venturing into the underwater environment. While originally the realm of daredevils and inventors, currently the number of active divers is estimated at over one to three million, although the actual number is unknown. While diving is now regularly carried out for recreational, commercial, and military purposes, there still remain significant hurdles to operating in the aquatic world.

One such hurdle that is frequently experienced by recreational divers is that of identifying the surrounding marine life. Many dive operations keep fish identification charts aboard their vessels for divers to consult after returning to the boat, but it's often difficult or impossible to recall each and every sight during the dive. Another complication is that fish often change appearances as they grow and adapt to particular environments [1]. This makes accurate identification dependent on the anatomical characteristics of the fish (body size, fin positions and shapes, eye position and size, etc.) in addition to the coloring.

A new software package called Goggle-based Overlay for Fish Identification, Selection, and Highlighting (GOFISH) is under development at the University of Delaware (UD) that will automatically track and identify underwater animals for recreational divers. This software not only displays real-time species identification through video overlays, but also logs identification information acquired during the dive.

Another obstacle to scuba divers is that of navigation without vision. The primary senses through which humans experience the underwater world are vision and tactile senses. Auditory signals are much less frequently relied upon due to our ear's inability to process underwater sound properly. In air, sound travels at roughly 340 m/s (1,115 ft/s). Underwater, however, sound waves travel at around 1500 m/s (4,921 ft/s), almost five times as fast as in air. While above the surface, the human ear uses the difference in arrival times of sound between the two eardrums to triangulate the source location, underwater, the time difference between a sound wave reaching the left ear and the right ear is so minute, we are unable to process the triangulation.

High turbidity, or reduced water clarity, often diminishes or prevents recreational dives and even some commercial dive activities. When visibility is reduced or completely eliminated due to suspended sediments (such as sand in the littoral region) or microscopic organisms called phytoplankton (such as diatoms), it is very difficult for a diver to determine both geographic position and orientation without some other form of sensory feedback.

At a depth of around 15 to 20 ft, suspended sediment in the Cooper River, north of Charleston, South Carolina, blocks all ambient light from the sunlight above. Scuba divers descending through this zone, even at noon on clear days, must be prepared with battery-powered electric lights to generate even two to three feet of visibility. Hazardous material divers encounter zero-visibility conditions on a normal basis where even specially designed underwater lights cannot penetrate the darkness. Public safety divers near ports and harbors also work in vision-denied environments as boat traffic causes particulates from the sea-floor to rise in the water column and severely limit the ambient light levels. Even recreational divers in the American Midwest winters find ice-diving to be a dark adventure due to the snow piled atop the frozen surface preventing light to reach the water [2].

In cases like these, divers must rely on tactile only cues to discover the environment around them. Blindly traversing an unknown environment, however, can have potentially fatal outcomes as the divers may unwittingly drift or swim into biological hazards [3], entanglement hazards, impalement hazards, overhead environments without an available direct

978-0-933957-40-4 ©2013 MTS

ascent to the surface, or for military divers, explosive hazards [4], [5]. While these situations are identified as severe risks, professional and military divers perform dives such as these on a daily basis. Even advanced recreational divers experience some of these black-out conditions in the course of their diving activities.

In an effort to reduce or eliminate tactile-only dive situations, the University of Delaware has begun development of the Diver Augmented Reality and Knowledge for Navigation and Vision (DARKNAV) software. This software package will provide divers with direct visual assistance during low or no-visibility situations.

Both the GOFISH and DARKNAV software packages will be incorporated into the new UD Underwater Augmented Reality (UAR) system. Augmented reality is the superimposition of additional information into a user's field of vision in real-time. Typically, this is accomplished by mounting displays or projection reflectors within a pair of eye-glasses. These screens display, in real-time, computer-generated graphics or information superimposed on the normal view of the world. In our case, computer-generated information for fish identification or navigational cues are presented inside a modified scuba mask.

This paper presents an overview of the research and development conducted at the University of Delaware on the novel GOFISH and DARKNAV software suites, the diver-mounted hardware modules of the UD UAR system, and briefly explores the challenges of underwater augmented reality.

II. System Overview

The UD UAR system includes three modules that can be incorporated into typical technical scuba diving setups (also known as rigs). Recreational divers using the GOFISH system need only the combined computation unit and battery pack, and the modified face-mask. DARKNAV users also need one additional module which provides inertial localization information.

Technical and military divers have come to rely on a rigid backplate of stainless steel or aluminum, rigged with webbing as the foundation of their scuba system [6], [7]. A buoyancy bladder, known as a wing, which provides lift for the diver is then bolted to this backplate, as are other diving accessories such as cannister lights, emergency air supplies, argon cylinders for dry-suit inflation, and more. Finally, the primary breathing gas supply cylinders are mounted to the backplate outside of the wing. (Figure 1).

The computational unit and battery pack are housed within the same anodized aluminum pressure vessel and connected to the face-mask via a single waterproof cable harness. Initial tests with the system demonstrate run times of almost five days with a single processor and a 12V 5Ahr lead-acid battery.

Since radio waves are attenuated near the water surface, GPS is unavailable underwater. Localization of the diver must be accomplished through either inertial-based measurements, acoustic triangulation, or a combination of the two. Finally, a suitable face-mask incorporating either a heads-up projection system or more simply LCD displays is worn by the diver and connected to the processing unit.

Fig. 1. Assembled technical rig with backplate, harness, wing, regulators, and double cylinders.

A. Battery Pack

The battery module currently consists of two 12V DC 5Ahr lead-acid batteries (Power-Sonic 1250 equivalents) enclosed in a hardcoat anodized (type III) aluminum 6061 waterproof pressure vessel (Figure 2). Wet-mate Subconn bulkhead connectors were used to distribute power to external system modules. The battery module is fixed to the scuba backplate via standard mounting hardware. Laboratory tests have demonstrated system run-times of approximately 70 hours of continuous operation based on the current battery pack, computational setup, and power distribution system. Typical recreational dives last between 30 and 90 minutes, while commercial and military dives may extend to several hours. In both cases, multiple dives are possible without the need to charge or exchange battery packs. It is expected that additional computational resources may be added to the existing system while maintaining run times over 24 hours.

B. Computational Module

The computational module of the UD UAR system is comprised of a Raspberry Pi (Broadcom BCM2835-based system on a chip (SoC)) Model B with 512MB RAM enclosed along with the batteries in the aluminum pressure housing. The system runs a Linux kernel with the May 25, 2013 release of the Raspbian "Wheezy" distribution, which includes hardware floating-point modifications (hard-float application binary interface). The default system configuration was modified to overclock the BCM2835 chip to 800MHz from the original 700MHz. This device is equipped with 26 General Purpose Input Output (GPIO) pins which can communicate and drive external electronics, in addition to two standard universal serial bus (USB) ports, an ethernet port, High-Definition Multimedia Interface (HDMI) and Radio Corporation of America (RCA) video outputs, and a 3.5mm stereo audio jack. The typical current draw of this device is approximately 0.2A or less, making it ideal for computationally intensive embedded applications. The Broadcom SoC generates very little heat which is easily dissipated through the walls of the aluminum housing.

Fig. 2. The battery module is configurable for both cylinder-mount and side-mount options. This image shows the side-mount configuration with removable carrying handle, pressure-relief screw, and main power toggle switch.

C. Localization Module

The localization module, currently in development, will contain the sensors necessary to locate the diver geographically. Mask orientation is determined seperately via a mask-integrated sensor. Diver velocities can be determined via a combination of diver-mounted Doppler velocity log (DVL) and a fiber optic gyro (FOG) such as the KVH DSP-1750; experiments are underway to determine the optimal mounting scheme and physical positioning for the DVL and FOG. Although it is well known that radio signals do not penetrate most liquids, the localization system includes a global positioning system (GPS) for surface operation to obtain an initial geographic position before submerging, and to back-propagate error-corrections when a new satellite fix is available upon each subsequent surfacing. While this will not influence mid-dive real-time visualizations, the geographic registration of the internal position map will be updated for export during post-dive activities such as debriefing and logging.

D. Face-mask

The full face-mask is the information display center of the UD UAR testbed and houses several important elements of the UAR system. Exposed to the ambient environment are a stereo camera pair, enclosed in individual pressure-housings, and mounted to the sides of the mask that provide the video input for the augmented reality system. Also integrated externally to the mask is an Ocean-Server OS5000 3-Axis Solid State Digital compass module which provides the mask heading, roll, and pitch at refresh rates up to 40Hz. In the interior cavity of the mask are the augmented reality displays which provide real-time video with computer augmentation to the diver. The current design is based on a highly modified Guardian Full-Face Mask. Initial in-water trials are expected during the winter of 2014.

III. Research

The open-source UD UAR testbed supports and encourages the development of novel augmented reality software packages through the use of industry standard components, design specifications, and detailed documentation. Two ongoing projects at UD each highlight different possible uses of UAR. The GOFISH project seeks to enhance recreational dives through real-time supplemental information, while the DARKNAV project demonstrates the use of augmented reality for commercial and military uses. Both projects address specific needs in the underwater community, but also give researchers the chance to work in a real-world environment not typically considered for this type of research.

A. GOFISH

The GOFISH project is an attempt to use real-time underwater video cameras, in combination with the UAR system to overlay contextual information regarding the diver's field of view. Once a fish is found in the video feed, it is tracked and submitted to the recognition algorithms for identification. If the fish is identified with a high level of confidence, scored by the template matching scheme, the fish is outlined and species information displayed in the diver's augmented display within the face-mask.

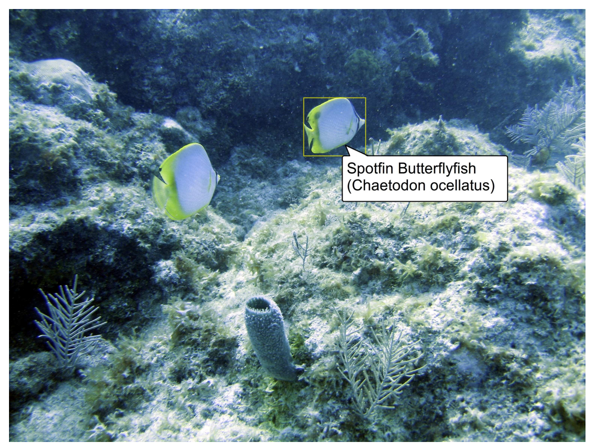

Fig. 3. After the tracking module locates potential animals, the template-matching module attempts to identify and present information about the animal. Here the tracking system was code-limited to one object per field-of-view.

The development of this system is planned in successive stages, each increasing the level of difficulty and sophistication of the system. Specifically, the first demonstration of this technology is the automatic tracking and identification (post-processed) of fish within the field of view (Figure 3) from a diver's hand-held video feed. Initial trials have been successful with limited training sets of fish images and carefully recorded video streams.

The second stage of development, currently in progress, includes efforts to enhance both the robustness and speed of target identification. Due to the limited power and computational resources available in the diver-mounted system, it is critical for the software to make use of memory in an efficient manner. To achieve the real-time video overlay, GOFISH uses the Open Source Computer Vision (OpenCV) library of machine vision functions to both process and generate the output video feed.

After successful testing of the enhanced code on the diver-mounted hardware, the system will be subjected to field tests in real-world environments.

The tracking of objects in video is a well developed application of machine vision, but the additional complications of camera motion and jitter, target motion, background motion (aquatic plants and other animals), and lighting constraints significantly increase the complexity of tracking fish underwater.

Real-time video is captured via the mask-mounted cameras and fed to the image-processing routines. These routines first apply a general color correction to recover the longer wavelength colors (red end of the visible spectrum) lost to attenuation. Optical flow is calculated (Figure 4) and used to determine transformation parameters in an image subtraction scheme.

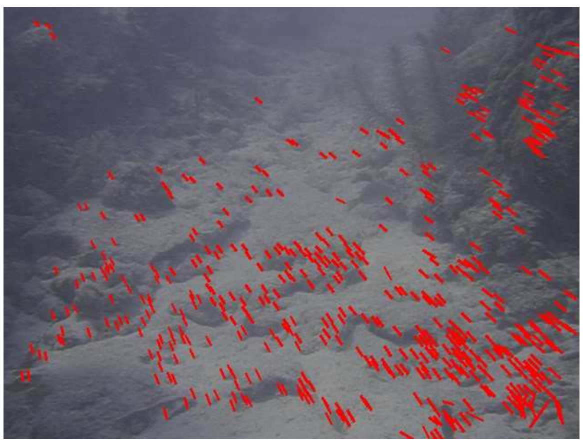

Fig. 4. Optical flow calculated between successive frames in the raw (color uncompensated) video sequence can be used to determine the camera motion transformation.

The subtraction scheme operates on two sequential images by determining the camera motion between images, and transforming (scaling, rotating, shifting) the first image to align spatially with the second image. Subtracting the transformed first image from the second image eliminates the (mostly) static background (Figures 5 and 6) and only portions of the view that have moved in the environment (excluding camera motion) remain [8], [9].

While subtraction removes most of the static background, aquatic plant life experiencing current-induced motions is often difficult to distinguish from animals in motion. This is overcome by noting the position of the tracked object in the previous frame and reducing the search region to an area near the previously tracked position. Once potential fish objects are identified, the region of interest containing the object is passed to a template matching routine as in [10]–[12]. Representative images from four species of fish were chosen from freely available images on the internet to serve as a limited training set to demonstrate functionality. Once identification is complete, pre-determined information is overlayed on the diver's visual display and identification information is stored in memory for post-dive analysis.

Fig. 5. Original image from diver video stream. The background in this image is fully static and any apparent motions arise from camera pose (location) changes.

Fig. 6. Result of sequential image transformation and subtraction. The region-of-interest (Bluegill fish) is easily located in the result.

B. DARKNAV

The DARKNAV project is technically more ambitious due to the additional complexities of simultaneous localization and projection (SLAP). The current research effort is focused on improving a diver-wearable module to perform inertial navigation. Commercially available diver-location devices typically consist of acoustic transponders which provide the bearing and distance to a diver-mounted pinger [13], but these systems require extra pre-mission equipment and deployment. Autonomous underwater vehicles have long demonstrated the ability to navigate accurately using self-contained sensors such as DVLs and inertial measurement units (IMUs) without the aid of GPS signals. In the GPS-denied environment, we must determine not only the diver's position in the environment, but the orientation and heading of the face-mask relative to the backplate-mounted sonar.

The mask-mounted digital compass (the Ocean-Server OS5000) provides mask heading, roll, and pitch. After obtaining an initial geographic location from a GPS signal at the surface, by constantly measuring velocities, accelerations, and rotations of the diver, an inertial estimate of position may be created. When the mask-based compass is combined with depth information and the inertial position estimation, a full descriptor of the diver's orientation and location may be assembled.

For this project, a priori knowledge of the geographic region in which diving activities will occur is fundamental. Pre-built 3D computer aided design (CAD) models are constructed to-scale of in-water obstacles and hazards using available means (such as sonar, previous hand-measurements, architectural drawings, etc.) and georeferenced, similar to satellite images for map mosaics.

Once the geographic position and orientation of the face-mask (i.e. camera viewpoint) are determined, it is a relatively simple matter to superimpose a pre-georeferenced 3D CAD model within the diver's video display (Figure 7). The accuracy of this system is dependent on the quality of the position/orientation estimate of the diver. It is well known that the inertial position estimation experiences drift (error) over time, but this error can be compensated for using known geographic references such as GPS at the surface or even underwater landmarks.

Even in highly turbid waters, features are occasionally visible underwater. These features may be used to correct position error if the features are recognized landmarks. Another means of absolutely positioning the diver is manual intervention from the diver. If visibility is at or near zero due to water conditions, the inertial estimations should help a diver navigate to a known location or object where the diver can reset the position estimation as if a GPS signal had been received. Visual and manual position intervention are an ongoing effort in the DARKNAV project.

IV. Conclusion

This paper described the new UD Underwater Augmented Reality (UAR) system and two application-specific software packages, namely, the GOFISH and DARKNAV suites. As the development of each software package continues, efforts will focus on extending and generalizing the selection and classification schemes in the GOFISH project and improving the inertial navigation and localization schemes in the DARKNAV project. Further investigations into reducing this error will lead to higher selection and recognition rates. Finally, improving the mask-integrated heads-up display (HUD) continues to be a priority.

The overarching research goal of the UD UAR effort is to provide a multi-use Augmented Reality (AR) testbed for UAR applications. To this end, we have reported the system design and two software architectures for augmenting scuba experiences with aquatic animal information and navigational references.

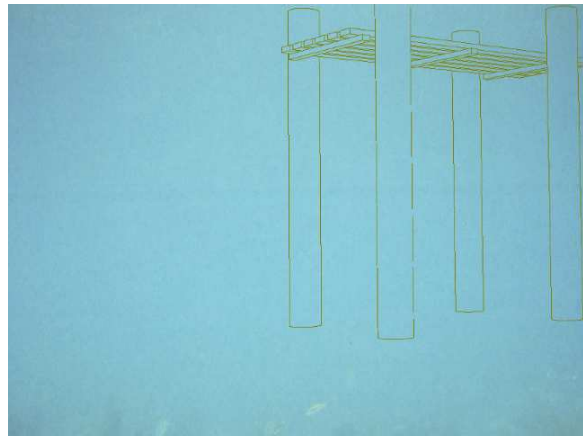

Fig. 7. 3D model of pier superimposed on highly turbid real-time video. The diver location is estimated and mask pose is measured to determine the appropriate transformation to apply to the structural model to simulate vantage point and perspective.

References

[1] M. Sugimoto, "Morphological color changes in fish: Regulation of pigment cell density and morphology," Microscopy Research and Technique, vol. 58, pp. 496–503, 2002.

[2] L. H. Somers, "Under ice scuba diving," Diver Education Series, Michigan Sea Grant College Program, vol. MICHU-T-86-008 C3, p. 70, 1986.

[3] ——, "Oceanography for divers: Hazardous marine life," Michigan Sea Grant Diver Education Series, vol. MICHU-SG-86-510, pp. 1–39, 1986.

[4] The Hazards of Diving in Polluted Waters. Maryland Sea Grant Publication, 1992.

[5] M. A. McGreal Jr., "An analysis of public safety diver fatalities," village of Wilmette Fire Department, Wilmette, Illinois, Tech. Rep., 2009, an applied research project submitted to the National Fire Academy as part of the Executive Fire Officer Program.

[6] NOAA, NOAA Diving Manual, 4th ed., J. T. Joiner, Ed. Best Publishing, 2001.

[7] USN, U.S. Navy Diving Manual, N. S. S. Command, Ed. United States Navy, 2008.

[8] B. D. Lucas and T. Kanade, "An iterative image registration technique with an application to stereo vision," in Proceedings of Imaging Understanding Workshop, 1981, pp. 121–130.

[9] C. Tomasi and T. Kanade, "Shape and motion from image streams: a factorization method," Tech. Rep., 1991.

[10] M. T. A. Rodrigues, F. L. C. Padua, R. M. Gomes, and G. E. Soares, "Automatic fish species classification based on robust feature extraction techniques and artificial immune systems," in Proceedings of Bio-Inspired Computing: Theories and Applications, 2010, pp. 1518–1525.

[11] C. Spampinato, D. Giordano, R. D. Salvo, Y.-H. Chen-Burger, R. B. Fisher, and G. Nadarajan, "Automatic fish classification for underwater species behavior understanding," in Proceedings of ARTEMIS 2010, vol. 1, 2010, pp. 45–50.

[12] J. Wilder, C. Tonde, G. Sundar, N. Huang, L. Barinov, J. Baxi, J. Bibby, A. Rapport, E. Pavoni, S. Tsang, E. Gargia, F. Mateo, T. M. Lubansky, and G. J. Russell, "An automatic identification and monitoring system for coral reef fish," in Proceedings of SPIE 8499, Applications of Digital Image Processing 35, A. G. Tescher, Ed., vol. 8499, no. 35, October 2012.

[13] RJE International, Inc., Dive-Trak Pro Diver Navigation System, dtpro, rev f, 08/09 ed., 15375 Barranca Parkway, Suite B107, Irvine, CA 92618, 2011.