Design of Modular Camera Tool for Mini Underwater ROVs

Michael Poretti, Bridget Benson
Electrical Engineering Department
California Polytechnic State University
San Luis Obispo, CA
mporetti@calpoly.edu

Chris Rauch
Rauch Engineering
Los Osos, CA

***Abstract*—Remotely operated vehicles are an essential tool for marine researchers and workers. Their robust nature allows them to serve a wide range of purposes, such as remote visual inspection or tool operation. Cameras are the main method for providing operator feedback to the surface. They enable an operator to accurately maneuver or handle objects up to thousands of feet away. Although large ROVs have cameras attached to their robotic arms for closer inspection of objects, min ROVs do not have cameras attached to their robotic arms because no camera tool has been specifically designed to support he low-cost, lightweight design of a mini ROV. Therefore, this paper discusses the design considerations, component selection, and system prototype of an affordable modular underwater camera tool for mini ROV robotic manipulators.**

Keywords—Remotely Operated Vehicle; Underwater Camera; Light Sensitivity; Mintron;

I. INTRODUCTION

Industries around the world employ underwater remotely operated vehicles (ROVs) for a wide range of research, inspection, and work. Such activities include investigating sea life, collecting data, or inspecting structures. ROVs offer different advantages depending on their size; they can be used as underwater workhorses or utilized for their quick and easy deployment [1]. Smaller ROVs are commonly employed for their relative cheapness and ease of operation compared to larger options [1][2].

Cameras are essential for remote operation of these vehicles since they serve as eyes to the surface. They serve two main purposes: remotely driving the ROV and visual inspection of underwater objects. Almost all ROVs come with a camera fixed to the main body, and may be on a pan/tilt mechanism. Some of the larger ROVs have maneuverable cameras attached to robotic arms, as seen in Fig. 1. For a size reference, an ROV that can use the arm shown in Fig. 1 would be the Schilling Robotics UHD ROV, which weighs over 10,000 lbs. These cameras are used for close inspection because turbulent underwater conditions make macro shots with the main camera near impossible [1].

Currently, mini ROVs do not have cameras attached to their robotic arms since no camera tool has been specifically designed to support the low-cost, lightweight design of a mini ROV [3]. A mini ROV like the SeaBotix LBV300-5 shown in Fig. 2, cannot use a several hundred pound arm like the Schilling TITAN 4 because its own weight is only 29lbs.

Thus, this paper describes the design of an affordable modular underwater camera tool for mini ROV robotic manipulators. The added functionality of a maneuverable camera to the mini class will make them much more versatile inspection tools, and therefore a viable option for a broader range of missions. This paper details the design considerations, component selection, and system verification of the modular camera tool.

II. DESIGN CONSIDERATIONS

The basic design considerations for an affordable modular underwater camera tool for mini ROV robotic manipulators are cost, light sensitivity, resolution, and pressure housing. In addition, the camera tool must be remotely interchangeable with other tools while the ROV is deployed.

Fig. 1. Schilling TITAN 4 manipulator with wrist camera option

Fig. 2. SeaBotix LBV300-5 mini ROV with simple robotic manipulator

A. Cost

More focus was put towards lowering cost so the end product is in line with the cost structure for mini ROV customers. The cost of the overall modular camera system, including the new robotic manipulator, should be modest compared to the $40k price range of mini ROVs. Another market to consider is marine research at universities, who have a more limited budget.

B. Light Sensitivity

The most important camera specification to consider for high performance is light-sensitivity [4]. A more light-sensitive image sensor within a camera reduces the need for a large amount of artificial lighting produced by the ROV. Less forward directed light will minimize the turbid water masking effect caused by reflection from suspended particles [4]. As a result, the image can have a greater depth of field [4] and appear clearer.

Different technologies have been developed over the years to increase light-sensitivity of an image sensor. Some examples are silicon intensified target (SIT) and intensified charge-coupled device (ICCD) [4]. Cost and light-sensitivity are a function of the image sensor technology, so it does not need to be considered directly. It suffices to compare the minimum illumination and cost of different options.

C. Resolution

Resolution, cost, and light-sensitivity have a close relationship. It is not possible to have all three at an ideal level. Great resolution and light-sensitivity come at higher cost, while great resolution and low cost come with worse light-sensitivity and so forth. Resolution is the flexible camera specification since low cost and high light-sensitivity are of upmost importance for this application.

Originally a high-definition camera was considered, but the monetary difference between a high-definition (HD) and standard-definition (SD) camera made the former option unfeasible. The technology involved in producing an HD camera that works in low lighting is currently very expensive. A suitable SD camera costs less than $100 while an equivalently light-sensitive HD camera costs over $500. It was decided that a standard-definition camera would be more appropriate for the needs of the mini ROV community.

D. Pressure Housing

The pressure pod has several design considerations that can affect its depth rating and the image produced by the camera. Using a stronger material such as titanium or high-grade steel rather than aluminum can increase depth rating. Another option to improve depth rating is to fill the pressure housing with an optically transparent fluid instead of air, allowing the housing material to be thinner [5].

The pressure pod can also be outfitted with either a hemispherical or planar lens. Hemispherical lenses allow for a larger field of view [6], but they are significantly more expensive and difficult to seal properly. A planar lens may produce more image distortion due to greater refraction [6], but are less costly in time and money to produce.

III. Component Selection

The design requirements are best met with the Mintron MTB CM3160 camera seen in Fig. 3. It boasts a light sensitivity of 0.2 lux at F2.0 for color and 0.03 lux at F1.2 for black and white, with a resolution of 520 Television Lines (TVL) and 600 TVL respectively with a cost of only $79. Other cameras with a suitable price and light-sensitivity come inside a housing meant for other applications, such as security CCTV systems. The MTB CM3160 does not require any modification to be used inside a pressure housing, reducing production time. The infrared filter, the black box left of the lens seen in Fig. 3, is removed when placed in the pressure housing. The removal of the filter gives the camera a square form-factor making it more suitable for a pressure enclosure.

The included large aperture, fixed-focal length lens serves the product's purpose well. It puts more focus on closer objects because its depth of field is shallower and located closer to the camera. Another effect of the lens is a wider field of view and a closer minimum focusing distance, which is necessary for inspection style shots.

A prototype pressure housing allows for some preliminary testing of image integrity of the camera. The housing is machined from aluminum to save prototyping costs as seen in Fig. 4. The prototype differs from the final pressure enclosure because it holds batteries to power the camera. This adds mass and weight that is unnecessary in the end product, since the camera will be powered by the ROV. The prototype allows for underwater testing without an ROV.

Using an optically transparent fluid can save weight for the pressure housing, but the weight benefits are offset by additional difficulties. A corrective lens is needed to prevent visual distortion [5]. However the refractive index changes with increasing pressure, which reduces image quality [5]. Therefore, an air-filled housing is employed because it is much easier to work with and lowers project cost.

Hemispherical lenses have an advantage in accurate image representation, but they are difficult to work with in practice [7]. A planar lens is a more prudent option for this project because it has a lower cost and is much easier to seal with a pressure housing. Hence, a planar lens is used in the prototype and will be used in the final product.

Fig. 3. Mintron MTB CM3160 standard definition camera

Fig. 4. Pressure housing showing planar lens with camera

IV. System Verification

Visual testing of the camera was first performed by itself in air to verify low-light performance. After proving low light capable, the camera is tested inside the pressure housing while underwater.

A. *Mintron Camera*

The camera's close range ability, color light-sensitivity, and black/white light-sensitivity was tested. The close range focusing ability of the camera does not have a sharp transition from clear to blurry, but rather depends on the user's definition of acceptable. The minimum focusing distance measures at 4.5 inches from the camera as shown in Fig. 5. This shows the ability for close-up shots, the main function of the camera tool.

A testing apparatus was created to verify the camera's performance in low light. It consisted of a variable ambient light source created using a strip of LEDs and a white fabric to disperse the light. Current through the LEDs is linearly related to brightness in lux as measured by a light meter. Light levels below 1 lux were calculated using extrapolation from the current measurement. Fig. 6 shows the cameras color performance at several light levels; Fig. 7 shows the black/white performance. The light performance does not change between color and black/white modes when holding the aperture setting constant, as expected when using a Bayer filter. An interesting note is the image quality at the reported minimum illumination specification; the image only shows outlines and no details are discernible. While this is disappointing marketing hype, the camera will still operate well in low light levels. For comparison, an iPhone 4S can only operate down to 3.7 Lux, using the same lower illumination criteria as the Mintron.

There are some visual distortions around the outer edge of the image known as barrel distortion. This can be attributed to the wide-angle lens on the camera, a trade off for greater viewing angles.

B. *Pressure Housing*

The prototype pressure housing allows for visual characterization, but differs from the final design in weight and size. Camera power comes from batteries contained in the housing, so the design can be tested without an ROV present.

Directly comparing an air view to an underwater view shows two differences: subjects appear closer in underwater shots, and barrel distortion is increased towards the edges. Fig.

Fig. 5. Minimum focusing distance is 4.5in. Closest distance before black to white transition is no longer sharp.

Fig. 6. Color mode performance. Top left: Full brightness at 36.2 Lux. Top right: Fading color at 11.5 Lux. Bottom left: Notable increase in noise at 1.15 Lux, Bottom Right: Image reduced to subject outlines at 0.27 Lux

8 is provided to demonstrate the increased barrel effect towards the edges of an image. The angle of view also decreased from 76º in air without the housing, to 60º underwater. The minimum focusing distance is unchanged from air to water.

The intended application of the camera is for close up inspection, not landscape shots. A planar lens matches a hemispherical lens in optical quality at the center of the image, and deviates more towards the edges of the image. The camera's application allows for maximum maneuverability around the subject, allowing the subject to remain centered. With this in mind, the cost effectiveness of the planar lens is more useful than the rectilinear quality of the hemispherical lens.

V. Conclusion and Future Work

This paper considered the design of an underwater camera tool while balancing cost with performance. To meet the design criteria, a highly light-sensitive standard-definition camera was housed in an air-filled pressure enclosure with a planar lens. Preliminary testing demonstrated the camera tool is highly light sensitive and effective for close underwater inspection while staying very affordable.

Future work will include fitting the camera with a F1.2 lens, testing in deeper ocean waters, and affixing it to a robotic manipulator arm of a mini ROV. Cost effective methods to reduce the barrel distortion will also be investigated.

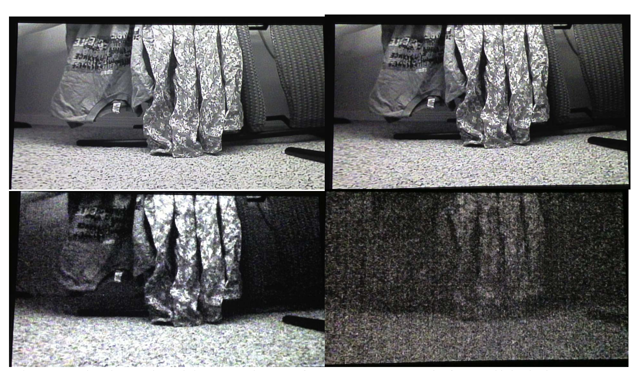

Fig. 7. Black and White mode performance. Top left: Full brightness at 37.2 Lux. Top right: Reduced brightness at 11.24 Lux. Bottom left: Notable increase in noise at 1.5 Lux, Bottom Right: Image reduced to subject outlines at 0.24 Lux

Fig. 8. Increasing barrel distortion from center to edges.

REFERENCES

[1] Costa, M.J.; Goncalves, P.; Martins, A.; Silva, E., "Vision-based assisted teleoperation for inspection tasks with a small ROV," *Oceans, 2012* , vol., no., pp.1,8, 14-19 Oct. 2012

[2] Sakagami, N.; Shibata, M.; Hashizume, H.; Hagiwara, Y.; Ishimaru, K.; Ueda, T.; Saitou, T.; Fujita, K.; Kawamura, S.; Inoue, T.; Onishi, H.; Murakami, S., "Development of a human-sized ROV with dual-arm," *OCEANS 2010 IEEE - Sydney* , vol., no., pp.1,6, 24-27 May 2010

[3] Jee-Hwan Ryu; Dong-Soo Kwon; Pan-Mook Lee, "Control of underwater manipulators mounted on an ROV using base force information," *Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on* , vol.4, no., pp.3238,3243 vol.4, 2001

[4] Stewart, D. J., "Conventional" underwater camera systems-an update," *OCEANS '94. 'Oceans Engineering for Today's Technology and Tomorrow's Preservation.' Proceedings* , vol.1, no., pp.I/176,I/180 vol.1, 13-16 Sep 1994

[5] Gelze, J.; Lehr, H., "On the way to a pressure-tolerant imaging system," *OCEANS 2011*, vol., no., pp.1,4, 19-22 Sept. 2011

[6] Kunz, C.; Singh, H., "Hemispherical refraction and camera calibration in underwater vision," *OCEANS 2008* , vol., no., pp.1,7, 15-18 Sept. 2008

[7] C. Rauch, Rauch Engineering, Los Osos, CA, private communication, April 2013