Underwater Laser Communication

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Underwater communication has presented unique problems because normal forms of communication do not function in the same manner underwater that they do above water. Lasers are a viable option as a solution to this problem despite the fact that lasers attenuate quickly in water. Underwater laser use was studied and tested to see how effective lasers could be at providing a method for underwater communication between SeaPerch ROV's. A green 532 nm laser was waterproofed and used as the laser source. A 3.5 inch convex lens was attached one focal length away from a photogate sensor and then waterproofed. The system was tested underwater at distances up to 60 feet. The sensor was only able to detect the laser when the angle of contact between the light and lens was perpendicular. The sensor was able to detect the laser light at the full distance of 60 feet, but not consistently. At distances up to 35 feet, the sensor detected the light 98.5 % of the time however from 35 to 60 feet that accuracy fell to 41.7%. These results suggested that the intensity of the light decreased significantly after 30 feet of travel. From the tests and research, lasers can be effectively used underwater at short distances as a form of communication between SeaPerch ROV's.

Introduction

Communication with underwater vehicles has always been difficult because standard radio communication is not a viable option underwater. Because sea water contains electrolytes like salt, it has a high electrical conductivity which inhibits the propagation of electromagnetic waves such as waves emitted at radio frequencies. Despite this, when using very low frequencies between 3 and 30 kHz, these radio waves can reach a depth of 20 meters. When using even lower frequencies, between 3 and 300 Hz, radio waves can penetrate into the water more than 250 meters. The problem with this is that the facilities required to emit these huge waves cover large areas of ground. This means that submarines utilizing this form of communication only can receive communication, they cannot send out information. The other downfall to this is that these large waves have a small bandwidth and cannot transfer very much data. These signals can only carry small text messages at about 450 words per minute.

Underwater acoustics are also used to communicate and navigate underwater, but there are a whole slew of problems related to this as well. The method of using sound underwater is effective when using sonar to navigate, however, when being used to communicate, sound suffers from multi-path propagation, slow data transfer and time delay due to the slower speed of sound underwater. These difficulties with both radio waves and sound signals leave room for a more efficient way to communicate in a subaquatic environment.

One possible solution to the problem is to utilize lasers. Lasers have the capacity to transmit data at high speeds, even when submerged in water, and can transmit much more data than sound waves or radio waves. A laser system would be able to collect and transmit data very quickly compared to the alternatives and can be potentially cheaper than using acoustic sonar equipment. This would open up the possibility to have underwater vehicles and even divers possess a means to instantly communicate with any other vehicles or diver around them.

Lasers do attenuate quickly when submerged in water, but not as quickly as infrared light or common radio waves. There is a tradeoff between distance and transfer speed. At a distance of 510 meters, 80 kbps of data transmission has been achieved whereas a 10 MHz band width has been achieved but only at a depth of 20 meters (Yoshida, 2011). Certain wavelengths of lasers also work better than others, particularly lasers using wavelength in the blue-green portion of the light spectrum. Blue or green light has been shown to propagate further than other light at depths up to 75 meters below the surface. At more than 75 meters, blue light can penetrate further than green light (Changchun, 2011).

Underwater laser technology is not new technology, but there are many obstacles that inhibit a more widespread use of underwater laser applications. There has already been research and test don to test the effects that lasers can have with communicating between underwater ROV's. This is desired so eliminate the need for tethering systems and cables (Cox, 2011). The two main problems with using lasers underwater are the principles that water absorbs light, and small particles in water can disrupt the path of light. This however does not mean that lasers are useless in the water. This research project will not explore an expensive solution to the problem, however it will explore a relatively cheap alternative to acoustic and radio transmissions as a way of underwater communication.

The purpose of this research is to develop an apparatus that has the capability to send and receive signals from laser light while attached to a SeaPerch ROV. No data will be transferred with this light, but the system will have the ability to be modified to do so if that is a desired result when reproducing the system. Ideally, this instrument would indicate when it detects a laser and be able to send back a signal at any depth or angle and have a range of 20 meters making it comparable to the research conducted by Yoshida in 2011. The range of communication will depend on the strength of the laser however, and this system is being designed for economic efficiency as well as performance. The sensor being used to detect

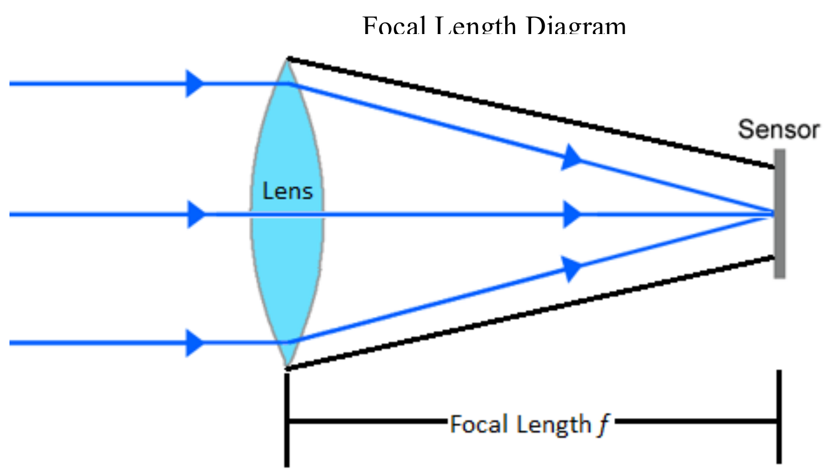

FIG. 1 The lens is positioned exactly one focal length away from the sensor to ensure that the light hits the sensor when it strikes the lens at exactly a 90 degree angle.

the laser would preferably be able to pick up a signal in any direction so that orientation is not a factor in whether or not a signal is received. It will have to achieve these goals and at the same time be able to attach to a SeaPerch and not affect the way that it operates underwater.

Methods

Some preliminary steps were taken before building a communication device was commenced. A 3.5 inch lens was acquired to be used as the target for the laser. Before it could be effectively used, its focal length had to be calculated so that the lens would refract the laser light into the sensor, as demonstrated in FIG. 1. If the correct focal length was not found, the sensor would rarely if ever register a signal. Two different methods were used to ensure accuracy. First, a lighter was held 12 inches away from the lens. A white piece of paper was then held on the other side of the lens and positioned accordingly so that the image of the flame was focused. The distance that the paper was held from the lens was 24 inches. According to the following lens equation,

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

where u is the distance from the lighter to the lens and v is the distance from the lens to the image, the focal length, f, was able to be found. After using the associated values and solving, f was found to be 8 inches. To test this result, the lens was fixed 8 inches from a surface and a laser was pointed at it. The laser was held perpendicular to the lens and moved around so that the light hit various points on the surface of the lens. The refracted light was then monitored and it was found that no matter where the light struck the front of the lens, the light always hit the same point after moving through the lens. This confirmed that the focal length was 8 inches.

Careful consideration was also given to the wavelength of light that the laser was to emit. Within the visible spectrum of light, wavelengths vary between 400 and 700 nanometers. The visible light with longer wavelengths, the red orange and yellow light, are absorbed much more strongly than the green, blue and violet light. For this reason, two 5 MW lasers were used that had wavelengths of 532 nm. After receiving and testing these lasers, one laser was found to be superior because it had a smaller, more focused beam. The size of the beam of light has been found to be an important factor in the range of underwater laser light. The degrading effects of underwater disturbances are greatly reduced for smaller beams (Hanson, 2010).

Setup

To achieve the desired outcome for this project, it was broken into two components, the emitting portion and the receiving portion. For the emitting part, a 5 MW 532nm green laser was used. Wires were attached to the power source to allow it to be activated from a distance one the laser was on the SeaPerch. The laser was then waterproofed and ready to go.

The receiving component was a little more difficult. A lens and photogate were used to make the target for the laser. This was done so that the laser would be able to hit anywhere on the lens and still be detected by the photogate. A plastic case was constructed to enclose the photogate and lens. Waterproof reflective tape was applied to the inside of this plastic case to increase the likelihood that light would reach the sensor at multiple angles of contact with the lens. The entire contraption was then waterproofed and prepared to be tested with a

Vernier LabQuest. The complete assembly can be seen in Fig. 2.

Underwater Communication System

FIG. 2 Completed components required for underwater later communication system.

Results

Above water, the apparatus performed almost as desired. When the laser light hit the lens orthogonally, the sensor would recognize the light every time it was tested, no matter the distance in between the laser and lens. However, as different angles of contact were tested, results were far from optimal. The sensor picked up light intermittently, even though a constant beam of light was shined onto the lens from various angles. As tests continued to be performed, there was no correlation between the angle of contact and the sensor triggering. Most of the time in fact, the sensor did not register that there was any light when the angle of contact was not 90 degrees. This proved that the reflective tape did have some effect, but did not produce consistent enough results to document.

Underwater, the sensor and laser performed admirably. The laser beam was clearly visible underwater because of all the particles in the water, but the strength of the beam did not appear to lessen. In the 20 yard pool that it was tested in, the sensor was able to sense the beam at the maximum distance of 60 feet as long as the beam was orthogonal to the lens. This result however was not achieved every time the laser was shot at the lens.

A total of 10 trials were performed at 5 foot increments in the pool to test the range of the laser and sensor. Fig. 3 contains the results of this test. From the figure it can be seen that the sensor was able to register the laser light up to 30 feet away with 98.5% accuracy. At distances greater than 30 feet, the sensor was not near as capable of sensing the light when the laser was lined up with it. At ranges from 35 feet to 60 feet, the sensor registered light contact 41.7% percent of the time. Overall, the accuracy of the sensor was 72.3% along the full 60 feet of the pool.

When different contact angles were tried underwater at a range of one foot, the sensor acted the same as it did above water. When the angle was close to 90 degrees, the sensor would occasionally trigger, but still not very frequently. When the angle was far from 90, the sensor never picked up the light source.

Discussion

These results were not as positive as predicted but the sensor and laser effectively operated underwater. The waterproof system was able to communicate at distances up to 60 feet as desired. However, the fact that the tape did not reflect the light strongly enough to trigger the sensor was disappointing, but not devastating to the outcome. One solution to the problem would be to use a more sensitive sensor.

Another problem was that the size of the lens made it more difficult to aim and hit from greater distances away. The 3.5 inch target

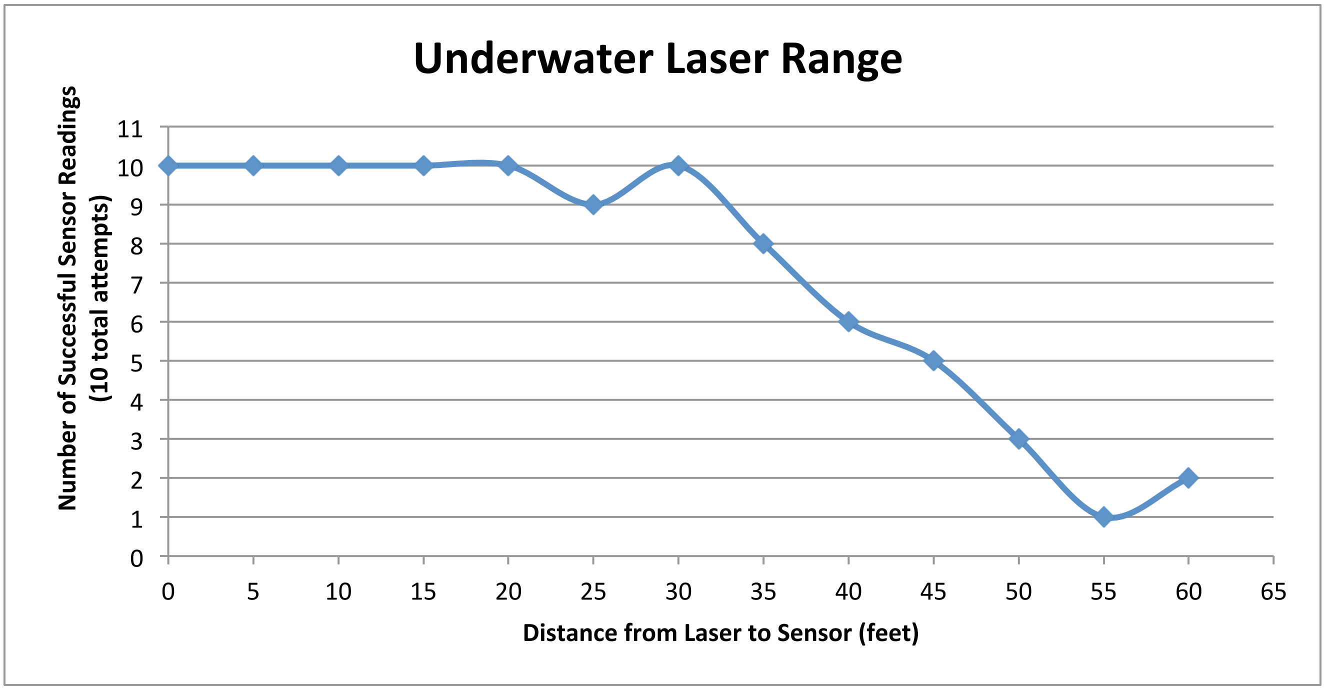

Fig. 3 This graph represents data obtained from testing the laser system underwater at specified distances away from the sensor. A total of ten trials were performed at increments of 5 feet from 0 to 60 feet.

area could have had some effect on the accuracy of the sensor at greater distances because it was difficult to gauge the exact contact angle of the light. The pool water was not perfectly clear either, which caused some problems when attempting to aim the laser at the small target. During the first test as well, the sensor and lens setup was found to be leaking in a couple places. The sensor was immediately taken out and another layer of liquid tape was applied. After this second application was finished drying, there were no more leaks and the sensor worked just fine.

Once the results had been obtained, it was easier to see where improvements could be made. There are other options for light sensors that could be utilized so that a lens is not required to focus the laser light. The lens proved to be a very small target to hit from 60 feet away. Using a larger lens is also another option, but that would mean a larger focal length and a larger enclosure. Photodiodes could have been used in multiple areas on the SeaPerch to create multiple targets as well. Plans will be made to implement some of these options in the future to increase the feasibility of using this laser communication system.

Conclusion

This underwater communication system that can be attached to a SeaPerch ROV functions properly. It is able to send laser pulses and detect when laser light hits the target. This apparatus is a good first step in the direction of using lasers as a form of communication in an underwater environment. As is, the system works well under ideal conditions with those ideal conditions being that the laser must strike the lens perpendicularly or there is no guarantee that the sensor will recognize the beam of light. In order for this system to be effectively used on an ROV, there would have to be another means of communication on board the SeaPerch that was capable of sending position information so that two SeaPerches would be able to line up and use the lasers. It would be effective if large amounts of data transfer were required in an underwater scenario. Lasers have already been shown to be able to transmit sound underwater. When a diver wants to communicate with another diver, tests have been done to turn sound spoken into a helmet into electrical signals and then passed through water via a laser to a receiver in another diver's helmet (Yaglimi, 2011). The possible uses that lasers have in underwater environments are growing. As the design is tested and tweaked, lasers have potential in becoming practical solution to the problem of underwater communication.

References

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Appendix

The following is the list of required materials and estimated cost:

	List of Materials	Cost
1	Silicone	$4
2	3.5 Inch Diameter Lens	$150
3	Empty 2 Liter Bottle	$1
4	Waterproof Reflective Tape	$5
5	HDE 5 MW 532 nm Astronomy Green Laser Pointer	$30
6	1 Package of Rubber Bands	$2
7	Liquid Electrical Tape	$4
8	Scissors	$5
9	Ruler	$1
10	60 ft. 18 AWG Wire	$12
11	1 X 16340 Battery	$2
12	Momentary N.O. Push Button Switch	$2
13	Soldering Iron	$30
14	Solder	$5
15	Electrical Tape	$2
16	Vernier Photogate	$70
17	Ziploc Bag	$1
18	Vernier LabQuest	$400
19	Vernier Digital Sensor Extension Cable	$15
		Total:
		$741