Analysis of Underwater Laser Propagation

Midshipman 1/C Zoe S Sobeck, Midshipman 1/C John Bolton Midshipman 1/C Shaun Shiotani, Midshipman 2/C Joe Vogeney

Professor Svetlana Avramov-Zamurovic, Weapons & Systems Engineering

Abstract

The purpose of this study was to observe laser light propagation through a watery medium and to understand the effects of that medium on data transmission fidelity. Data transmission was simulated through the use of an Optical Chopper, which physically broke the beam at a set frequency to simulate a digital signal being passed via carrier wave. Furthermore, two different types spread laser beams, Spatial Light Modulated and Gaussian, were compared to determine which was superior at delivering the most complete digital signal. Performance was measured in the percent error of the data transmission. As expected the turbid water transmission had significantly higher percent errors than those in calm water.

Background

Current underwater acoustic communication does not offer high data rates. The exploration of underwater optical wireless communications (UOWC) as a solution to the challenges of underwater communication is of considerable interest to scientists and the military alike. Communication between buoys, unmanned underwater vehicles (UUVs), ships, submarines, and divers can all benefit from UOWC especially if cheaper, more secure high data rate communication can be achieved [1]. UOWC employs optical wavelengths to transfer information between dedicated point-to-point links. Optical waves offer advantages like high rates of data transmission, secure links, small scale of transceiver components. Optical wireless transmissions use modulated optical beams in order to establish short, medium, or high frequency communications. Performance and reliability is dependent on weather and oceanic conditions between the receiver and the transmitter.

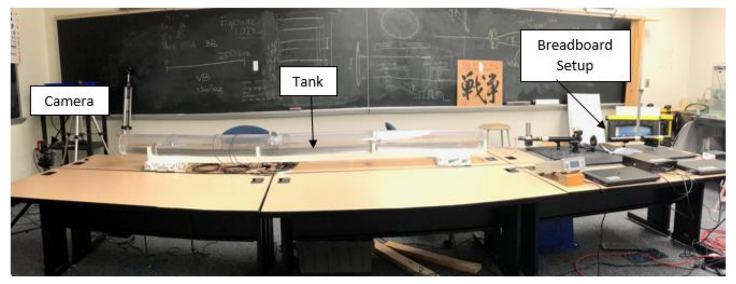
Experimental Setup

Equipment

Laser Source
- Metal Breadboard with Threaded Holes
- Melles Griot 25-LHP-213-249 Serial NO: 4324FN-1 1mW Maximum @ 632.8nm
- Mounts Required to fix lasers and expander onto Breadboard
- Power Sources for the Lasers
- EL-25-20X-A - 20X Optical Beam Expander, AR Coated: 400 - 650 nm
- Optical Chopper
- Iris Diaphram
- Meadowlark Optics Linear Series Spatial Light Modulator

Camera
- 340M-GE - Fast Frame Rate VGA Monochrome Scientific Camera with Standard CCD Sensor, GigE, Navitar TV Zoom 7000 Optical Lens
- Power cord for camera
- Data cable for Camera
- Camera Compatible Laptop
- Adata Hard drive

Additional Supplies
- Laptop for Image Analysis
- 96 in Cylindrical Water Tank with 5.5 in diameter
- Water Pump



Experimental Setup

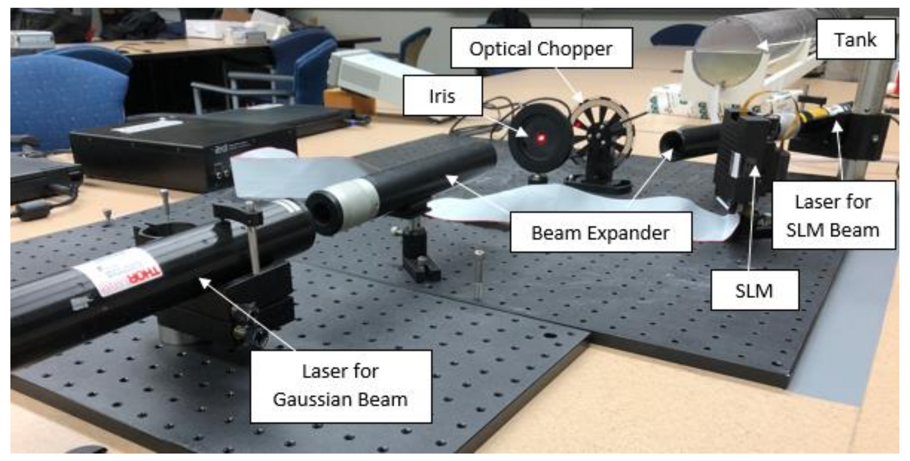
Acknowledgements

Thanks to Norm Tyson and Joe Bradshaw

References

[1] S. Arnon, "Underwater Optical Wireless Communication Network," *Optical Engineering*, 01-Jan-2010. [Online]. Available: https://www.spiedigitallibrary.org/journals/optical-engineering/volume-49/issue-1/015001/Underwater-optical-wireless-communication-network/10.1117/1.3280288.full?SSO=1#ArticleLinkReference

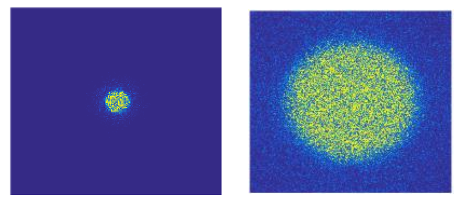
Methods



Mounted Laser Setup

Prior to conducting the various trials the optics breadboard was setup with the lasers (with Gaussian and SLM beam type) and the expanders mounted. The Iris was adjusted to limit the aperture of the beam to fit within the width of one of the Optical Chopper's slots.

A Spatial Light Modulator (SLM) modulates light according to a fixed spatial (pixel) pattern, referred to as a screen. The SLM cycled at 333 Hz, which relates how often the location of the beamlet changed.



(Right) Non-Expanded Beam undergoing Spatial Light Modulation. (Left) Expanded Beam undergoing Spatial Light Modulation

Data Collection Procedure

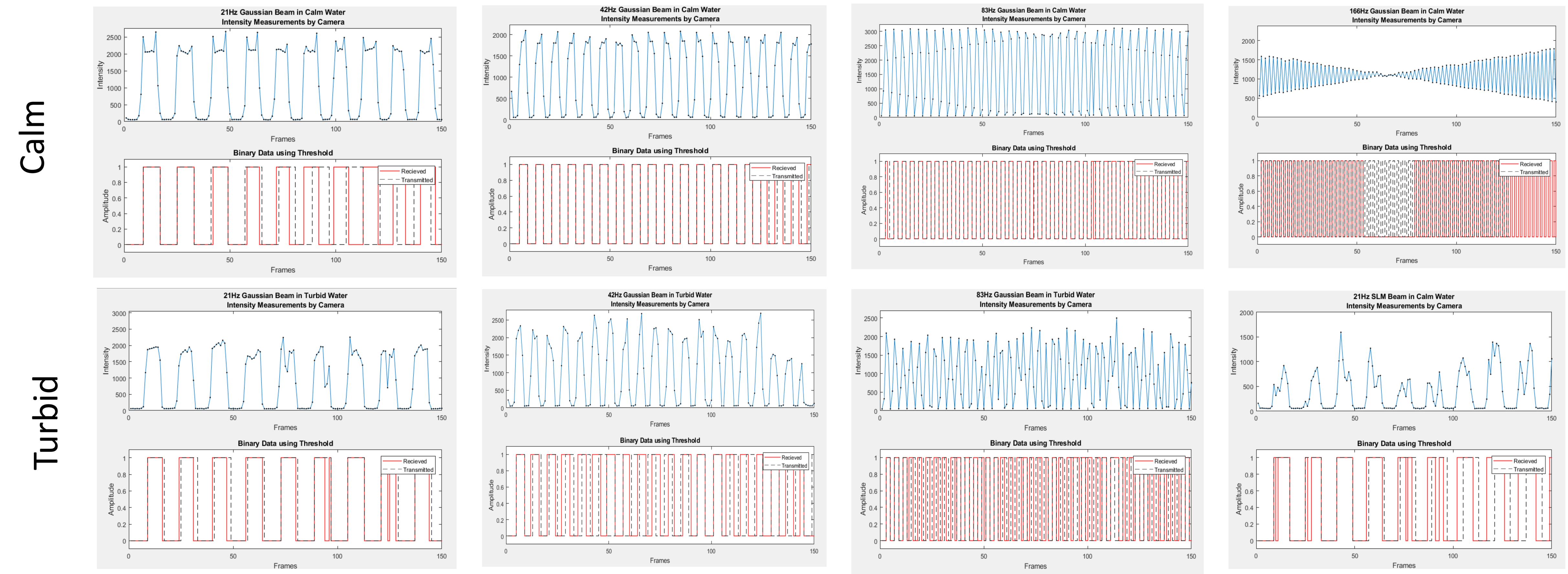
- The Optical Chopper was set at the desired data transmission rate, but not started.
- All ambient light was removed from the room and the camera parameters were set:
  - Exposure Time: 3.000 ms (330-335 FPS)
  - Min Light Intensity: 815
  - Max Light Intensity:1550
  - Gain: 84
- With the camera in full frame, the laser was shone on to the camera, and the brightest spot is located.
- The camera frame is reduced to capture only nine pixels (3X3), with its origin centered on the laser's brightest point
- If the SLM is being used, it is started at this point.
- The chopper is started and the camera begins to recording the data transmission.
- At around 2000 frames, the camera stops recording and the data is save as a .tif file. Data was recollected if there were any dropped frames

Data Analysis Procedure

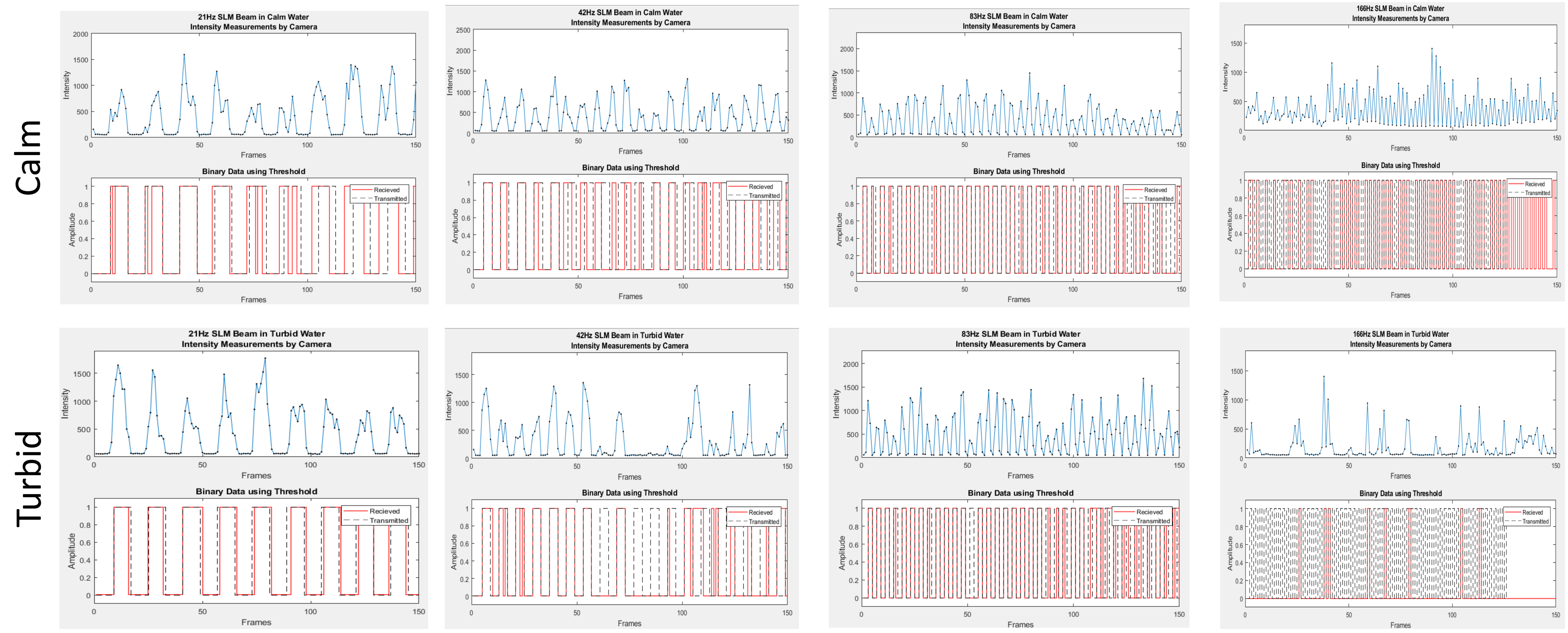
- In MATLAB the received data tif files were uploaded and run through a script producing
- The received data was thresholded so values above and below the mean value of the received data was represented as a one or a zero
- An array was created given the period and camera rate that generated a representation of the transmitted data
- The thresholded received data was plotted against the transmitted data
- The received data was indexed to start at the same time as the transmitted data
- The first 150 frames were analyzed for each frequency at the given conditions and beam type
- The percent error was calculated and plotted for each scenario through the comparison of the transmitted and received data

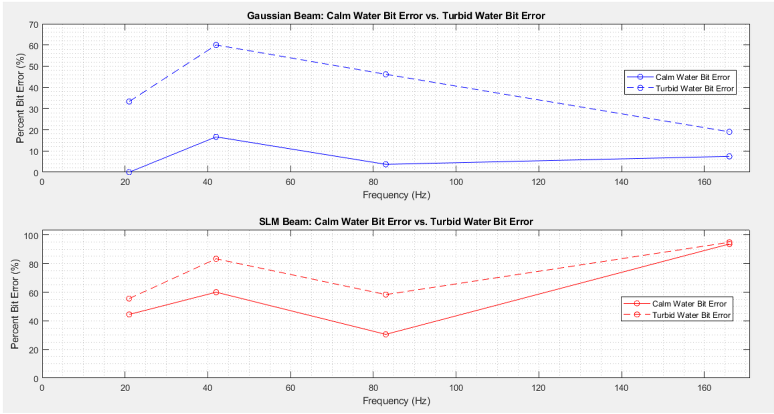
Results

Gaussian Beam



SLM Beam





Conclusion

The influence of water turbidity on the propagation of a laser is key in the study of the influence of the environment on laser propagation. Our experimental studies explained how turbidity can have a drastic impact on how laser beam propagate through water. This was found using intuitive analysis of the binary data from the intensities of light. Additionally, it was found that at higher frequencies, more errors occurred between transmitted and received data. In the additional experimental trial, with an inputted audio signal, turbidity had a great effect on the transmission of audio data through the water. Without turbidity, however, there was little effect on the audio transmission.