ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.6, Pages : 290-293 (2013)
Special Issue of ICETEM 2013 - Held on 29-30 November, 2013 in Sree Visvesvaraya Institute of Technology and Science, Mahabubnagar – 204, AP, India

Using Laser Communication Above Water and Underwater

K.Rajeswari and Kavitha P

INTRODUCTION

There is a growing need in maritime applications to quickly transfer large volumes of information between different units or in a sensor network. Radio frequency (RF) channels and satellite links on ships are often limited to data rates of some hundreds of kilobits per second to some megabits per second. Laser links offer the opportunity to overcome these restrictions for optical line-of-sight communications due to the very high frequencies used and, when compared to conventional RF links, the angle of the transmitting laser beam is small. Restrictions arise due to precipitation, like rain or fog.

Speed limitations are more pronounced underwater. Underwater acoustic modems can transfer data up to a few kilobits per second over distances of some kilometers, depending on the channel characteristics and the frequencies used. Lasers operating in the blue-green spectral range of the electromagnetic spectrum offer an alternative to realizing much higher data rates. Depending on the turbidity of the water, communication ranges are limited to 10 to 100 meters.

To address the possibilities and restrictions of using laser links in networks, with emphasis on naval applications like communication in a navy convoy or between a submarine and an autonomous underwater vehicle (AUV), the German Ministry of Defence’s Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71-FWG) has been studying marine data transmission.

(Left) A laser communication terminal onboard a German naval ship. (Right) The receiving terminal’s infrared camera observes a laser beam at sea. (Images courtesy of WTD 71)

Laser Link Development and Testing
In 2006, the U.S. Naval Research Lab carried out sea trials between two carriers equipped with a new generation of laser communication terminals (LCTs) in the U.S. In Germany, two identical

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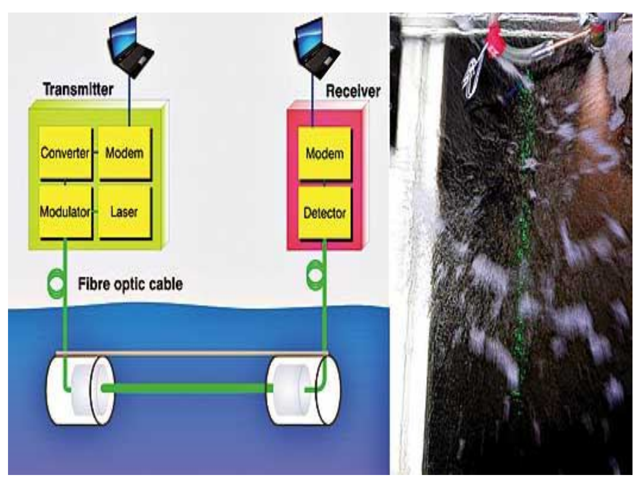
LCTs were built in 2007 together with Carl Zeiss Optronics (Oberkochen, Germany) on the basis of a research and technology study by WTD 71-FWG.

Each terminal is integrated on an agile stabilized platform, able to quickly compensate for the movements of a ship at sea. Both LCTs include two identical laser transmission channels in the near-infrared, which reduce atmospheric turbulence effects, as well as an infrared camera and a retro reflector for coarse and fine optical tracking of the outstation. The receiver consists of an aspheric lens and a fast photo diode. The system, designed for a data rate of 100 megabits per second, needs only a power supply and an Ethernet connection.

German experiments took place between a land station and ships in the Baltic Sea. In 2008, one terminal was fitted onboard a multipurpose vessel from WTD 71-FWG and, at the end of 2009, one was placed on a German navy auxiliary ship. Runs were performed to measure the range dependence of the bit rate, the tracking stability of the laser link and the bit error ratio (BER), which is the number of bit errors divided by the total number of bits sent. As environmental parameters of the marine boundary layer play a significant role in laser performance, researchers recorded visibility, sea temperature and air temperatures at different heights to allow the calculation of the propagation conditions for the laser beam.

During the trials, two different applications that required high-data-rate links were tested: Duplex video conferencing and file transfer. The measured BER in these applications was well below 0.01 percent for distances up to 10 kilometers, and net bit rates achieved 90 megabits per second in trials.

At longer distances, the BER increases. Under trapping conditions behind the geometrical optical horizon, the net bit rate at 24 kilometers distance still remained three megabits per second. Moderate rain (two to three millimeters per hour) reduced the maximum range by 17 percent, while heavy rain caused the free space optical link to break down. The mean availability of the laser link during the land and sea trials taking place from 2007 to 2010, which included different weather conditions, was about 80 percent.



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(Left) Diagram showing the experimental setup. (Right) A laser beam in a test tank is disturbed by air bubbles that are injected from outside. (Images courtesy of WTD 71)

Underwater Laser Communication For testing underwater laser communication, a continuous wave laser operating at 532 nanometers wavelength was chosen. In coastal waters with high turbidity and high content of organic matter, the green light attenuation is less than that for blue laser light, making blue preferable for operations in clear water masses of the open ocean.

Digital data from a notebook computer can be transferred via Ethernet to a modem of the transmitting unit of the underwater communication system. A converter drives an acoustic optical modulator (AOM), which is responsible for the intensity modulation of the laser beam. The system was designed for a data rate of 10 megabits per second. The modulated laser light was transferred via a fiber optic cable to an underwater housing that contains a collimator. The transmitted laser beam passes a distance of three meters in the water column before it is coupled back into another fiber optic cable. With the help of a detector and a second modem, the optical signals are converted back to a digital data stream.

The first tests were performed at WTD 71-FWG in 2009 in a basin and at a harbor mole. The water turbidity was chosen to comply with brown water conditions. After three meters of propagation, only 12 percent of the laser intensity remained. The path was further disturbed with injected air bubbles, which simulated breaking waves or the wake of a ship. As the laser beam diameter of 18 millimeters was large compared to the air bubble radius, damping by a factor of two was moderate compared to when no bubbles were present. In the basin and at the harbor mole, video streams and files were transferred with data rates between seven to 10 megabits per second. BERs remained less than 0.0001 percent. Allowing BERs up to 0.01 percent, the underwater laser could achieve a 10- to 20-meter propagation path under these conditions.

Conclusion

Future Developments Free-space optical links have proven to be an effective addition to established communication technologies, both above water and underwater. They allow much higher data rates in line-of-sight communication. At the same time, a host nation's approval of frequencies is not necessary. With their moderate laser beam power, LCTs have a low energy consumption and fall in the eye-safe region sightly above 1.5 micrometers, resulting in a nominal ocular hazard distance of zero meters. The main restrictions on laser links are caused by harsh environmental conditions.

For a higher data throughput in the gigabit regime, multiple-input multiple-output concepts are under discussion, using many transmitting and receiving units on each terminal. Hybrid systems, including an additional RF link, help overcome operational restrictions.

For underwater communications, a further miniaturization of terminals will

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be helpful, especially for the integration on AUVs. Finally, for applications on existing network infrastructure, easy-to-use Web interfaces must be developed.

Underwater laser communications are still being tested, while LCTs for above-water communications have reached demonstrator status. Within the next decade, these laser link technologies should be easily applicable in maritime environments, just like when they were applied in urban environments some decades ago.