Water Pollution Investigations by Underwater Visible Light Communications

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ABSTRACT
Underwater visible light communication can be used to measure the quality of the transmission medium not only for communication. We used three different LEDs for communication and measured the amplitude of the detected signal. The measured value can be compared to a reference point and the transmission medium caused attenuation can be calculated. There is a connection between the attenuation and the pollution of the water. We will show that the type of the water can be identify if only the attenuation is measured.
Keywords: visible light communication, underwater visible light communication, water contamination, water pollutions, VLC, U-VLC.

1. INTRODUCTION

Visible Light Communication (VLC) gets more and more attention in the last decades. However, most researches are focused to use it indoor as an extension of the Wi-Fi network or a part of an indoor navigation system [7]-[8]. There are many well-tried communication techniques in the free space, which will be not easy to change a VLC link. VLC can make the break out in the underwater communication. The speed of these communications is a few hundred kbps. A VLC link can rapidly increase the speed of an underwater communication link. There are many underwater cases, where the communication would be beneficial such as diving, checking the bottom part of the offshore oil platform by AUV (Autonomous Underwater Vehicles). These applications require a high speed connection between the transmitter and the receiver and a small size communication device. The LED (light emitting diode) based VLC link can serve these requirements.

However, the VLC link can be used for measure the environment not only for communications. The channel caused attenuation can be measured at the easiest way. If there is a connection between the detected power and the channel type (e.g. it is tap water or salty water), the quality of the medium can be determined. It make possible to detect pollution in the water without any expensive investigations in a laboratory.

In this paper we investigate the connection between the detected power of the emitted light and the different kinds of polluted water, where it was propagated. To check our conception we make a small test system for the measurements which will introduce in Section 2. In Section 3 can be found the measurement results of our system. Various types of water and pollutions were investigated e.g. tap-water, soapy-water, salty-water and mineral-water by measuring the attenuation of the signal, in order to show that the pollution type inside the water can be identified.

2. TEST SYSTEM

In Fig. 1 can be seen the schematic of our test system. We used a 60×60×30 cm (width-length-height) aquarium and it was fill up with different type of water. Our transmitter and receiver were put inside to the aquarium. The attenuation of the light in the water has minimal point at the green and blue colour [3]-[4]. Therefore in our transmitter we used these colours. A red LED was used as a third colour in the measurements, because these three colours are the bases of the vision. The transmitter side is responsible for the conversion of the electric signal to an optical signal. In our case we used power LEDs as the light source, and in order to control the light intensity (and also maintain linearity) we applied a voltage-driven current controller circuit. We used LEDs made by one specific manufacturer, in our case it was the AVAGO®'s 3 W Mini Power LED series. The LED was modulated by a square signal at 50% duty cycle to simulate the data transmission. The properties of the LEDs can be seen in Table 1. However, the efficiency of the LEDs are different, it will not affect the system. The distance between the transmitter and the receiver was increased and the detected signal amplitude was measured. The reference point was the closest distance at each colour, that is why the efficiency was not affected our measurement. The distance was increased or decreased by moving the transmitter.

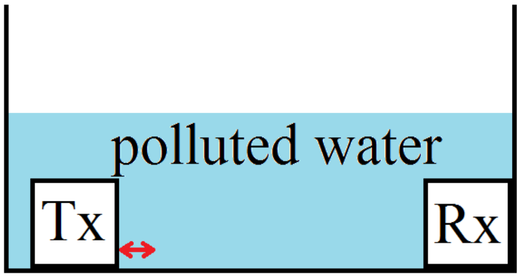

Figure 1. Schematic of the test system. Tx: transmitter, Rx: receiver.

Table 1. Characteristic values of the LED properties [1].

LED Colour	**Wavelength peak [nm]**	**Luminous Efficiency [lm/W]**	**Forward Voltage [V]**
Red Orange	615	65	2.4
Green	525	70	3,6
Blue	460	22	3,6

The transmission medium was 4 kinds of water: tap-water, mineral-water, soapy-water, salty water. The light from the transmitter was propagated through the medium, then it was detected by a receiver.

It converts the optical signal to electrical signal handled by a simple PIN photodiode. The detected signal was amplified by a two-stage amplifier circuit. The photodiode used in our measurements was an Optek OP913SL photodiode. This photodiode has a relatively large active area with added lens, so its parasitic-capacitance is quite big (few 100 pF), that is why we focused on the 500 kHz frequency. Photodiode with faster response can be used, but it will decrease the amount of the detected light, because of the smaller active area.

3. MEASUREMENTS

Figures 2 and 3 show the amplitude changes of the signal in different conditions of the water. In the measurements the distance was changed between 30 cm and 60 cm. The power of the light decreasing exponentially, therefore an exponential curve can be fitted to the measured values (dotted gray curve). The equation of the fitted curve can be in the following form:

$$y(x) = ae^{bx} + c \tag{1}$$

Determining the values of a, b and c we can identify the type of the measured water.

3.1 Tap-water

In the first measurement, the aquarium was filled up with tap-water up to the water level reached 15 cm. Under this height of the water the reflection from the water surface highly affect the measurement. The tap-water in Hungary is drinking water, and the following table [2] summarizes the limits of each component in tap-water regard to the health-care regulations.

Table2. Tap-water components [2].

Element	**Limit**	**Element**	**Limit**
Free active chlorine	-	Nitrite	0.1 mg/l
Chloride	100 mg/l	Ammonium	0.2 mg/l
Iron	200 µg/l	Hardness	50-350 mg/l CaO
Manganese	50 µg/l	Conductivity	2500 µS/cm
Nitrate	50 mg/l	pH	6.5-8.5

$$B_{500}^{tap}(\boldsymbol{x}) = 38966\, e^{-0.1462 \cdot x} + 339.71$$
$$R_{500}^{tap}(\boldsymbol{x}) = 19103\, e^{-0.0967 \cdot x} + 355.2$$
$$G_{500}^{tap}(\boldsymbol{x}) = 5901.1\, e^{-0.0822 \cdot x} + 175.65$$

The above mentioned equations were calculated from the measured data, which can be seen in Fig. 2. The bottom right index stands for the measurement frequency in kHz, and the top right index stands for the water type. The results are similar to the theory. Red light has larger attenuation than the green and blue.

3.2 Mineral water

This time we wanted to know the exact composition of the water, therefore the aquarium was filled up by mineral water. The following table (Table 3) shows the values of each component in it. Some further information could also be found on the bottle such as: Nitrite and nitrate are not detectable and the pH value of the water was 7.4. This value is roughly at the middle of the limit for tap-water. The measured curves can be seen in Fig. 2.

Table 3. Mineral water components.

Element	**Concentrate [mg/l]**
Ca^{2+}	63
Na^{+}	21
Mg^{2+}	26
HCO_3^-	400
Total dissolved solids	520

The equation of the fitted curves for the three colours:

$$B_{500}^{mineral}(\boldsymbol{x}) = 16838\ e^{-0.1060\cdot x} + 282.07$$
$$R_{500}^{mineral}(\boldsymbol{x}) = 14080\ e^{-0.0909\cdot x} + 338.22$$
$$G_{500}^{mineral}(\boldsymbol{x}) = 6363.9\ e^{-0.0869\cdot x} + 177.26$$

3.3 Soapy water

The condition of the water in the next measurement was 'slightly soaped', which means 10 grams of liquid soap was inserted in 22.3 litre tap-water. This tincture was of 0.045 weight-percent (with approximated weight of tap water as 1 kg per litre). Figure 3 shows the measured curves. The equation of the fitted curves for the three colours:

$$B_{500}^{soapy}(\boldsymbol{x}) = 11160\ e^{-0.0954\cdot x} + 153.59$$
$$R_{500}^{soapy}(\boldsymbol{x}) = 18642\ \mathrm{e}^{-0.0997\cdot x} + 279.29$$
$$G_{500}^{soapy}(\boldsymbol{x}) = 8206.4\ e^{-0.0941\cdot x} + 127.09$$

3.4 Salty water

At this time we wanted to emulate the salinity of the seawater, which is about 3.5 %, approximately 35 g/l, according to reference [5]. In this measurement we were still using 22.3 l water, and 780 g added salt.
The measured curves can be seen in Fig. 3. The equation of the fitted curves for the three colours:

$$B_{500}^{salty}(\boldsymbol{x}) = 6905.1\ e^{-0.0784\cdot x} + 189.6$$
$$R_{500}^{salty}(\boldsymbol{x}) = 4544.6\ e^{-0.0580\cdot x} + 244.05$$
$$G_{500}^{salty}(\boldsymbol{x}) = 10084\ e^{-0.0978\cdot x} + 152.04$$

4. COMPARING THE RESULTS

From the measurement we can see that red light suffers the largest attenuation in all cases like in [3]-[4]. The main difference between the tap-water and the mineral water is the amount of dissolved manganese and nitrate, manganese amount in tap-water is around 50 µg/l and 26 mg/l in mineral water. Regards to the label on the mineral water nitrate cannot be detected in mineral water. This way we can only compare the manganese values, as these values were given. The result of these measurements was that the blue coloured LED's received signal strength increased, and red-orange coloured LED's signal decreased significantly.

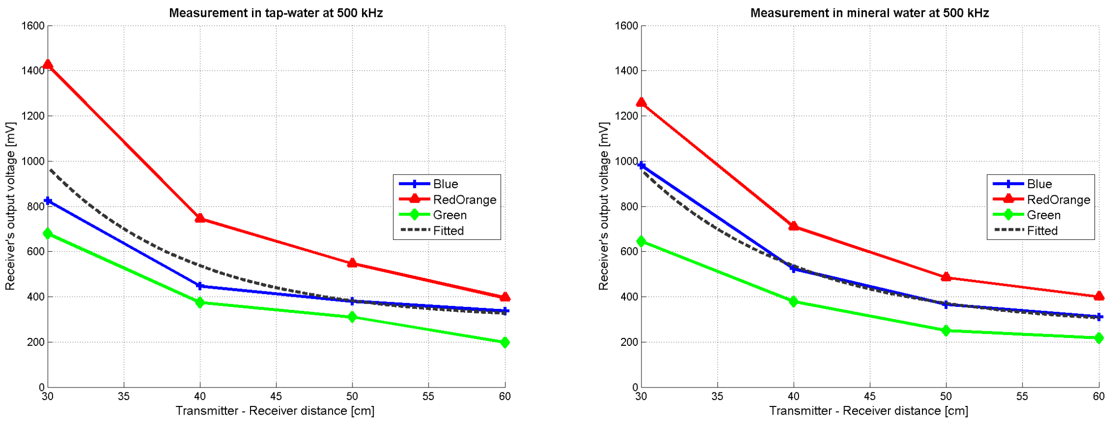

Figure 2. Left: output voltage level vs. distance in tap-water.
Right: output voltage level vs. distance in mineral water.

We can also state that the green coloured LED's signal strength was not that sensitive to the changes of the water type (unlike the case of red-orange and blue LEDs), but if we look closer on the salty graph we see that the output voltage is a little higher (if the distance is 30 cm), than in other cases. This phenomenon is probably caused by the different scattering factor of the salty water. The blue and the green coloured LED's light is scattering the most in the water. We can see clearly that the red orange colour has the lowest signal in the case of salty water. Compared to mineral and tap-water, salty water had the lowest exponent-factor (-0.058) in case of the red-orange LED. We can see that the exponent factors are highly influencing the range of the underwater VLC link, and these exponent-factors can be calculated from measured values. If we create a reference by measuring these exponent-factors in e.g.: tap-water we can use these as a reference, and compare this to other water type exponent factors. These factors changed significantly in some cases so it is reasonable to make this comparison based on the exponent-factors.

However, only one colour is not always enough for identifying the pollution in water as can be seen from the equations in Section 3, so further measurements are necessary with different LEDs. The case of blue and red-orange measurements in soapy and salty water shows that, if one colour's voltage level is increasing or decreasing does not mean that the other colour's voltage level will act the same way.

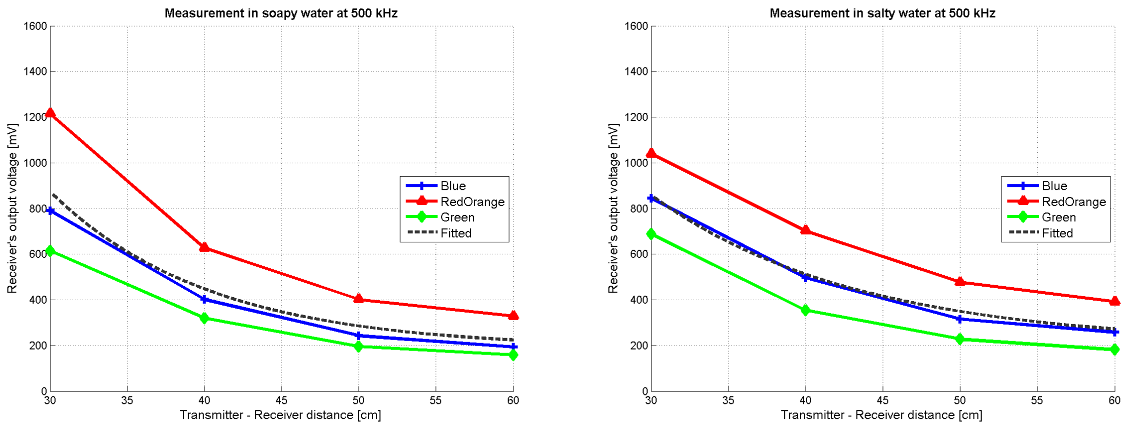

Figure 3. Left: output voltage level vs. distance in soapy water.
Right: output signal level vs. distance in salty water.

5. CONCLUSION

Our results showed that this pollution identifying method needs, at least three different coloured LEDs. As we saw before only one curve was not enough to identify the water type. The other prerequisite of the process is to make a reference measurement. Our recommendation is to take measurements by each colour at three different points in one line, and this point will be located near the halfway of the max operation distance. This method needs further investigation, where the reflection caused signal amplitude changes are took into consideration too, because it has high effect to the transmission.

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