

AN OPTICAL SENSOR SYSTEM FOR EARLY BACTERIA DETECTION IN DRAIN FLUIDS

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Abstract—This paper presents a miniature optical measurement system that detects the presence of bacteria in drain fluid at an early post-operative stage. The role of the detection system is to give information on the status of the drain fluid directly after surgery. In this way, clinicians are able to assess the health condition of the patient and to take the appropriate measures to prevent severe infection in the abdominal cavity, which can lead to complications and in some cases, death. This monitoring device consists of a near-infrared LED, a photodiode and a sample holder, which is placed between the two optical components. The absorption of light by the sample is a measure of the contamination.

Index Terms—Absorption, bacteria detection, drain fluid, near-infrared, LED, photodiode

I. INTRODUCTION

CONNECTING the two ends of a colon after a surgical resection can cause anastomotic leakage. Problems can occur when stitching the two ends of the colon together, and these can lead to a defect in the growth of the intestine wall. In most circumstances this will eventually cause leakage. In this case, the contents of the intestine enters the abdominal cavity of the patient and due to the non-sterile environment, this leads to multiple organ failure, sepsis and death. The mortality rate of patients who have had these complications is 33% [1].

A prophylactic drain tube is placed at the surgery site to eliminate body fluid, which flows passively through the drain and is also used for monitoring purposes. This body fluid consists of peritoneal fluid (which is the accumulated fluid in the abdominal cavity), wound fluid and blood from the surgical site (Figure 1). A post-operative analysis of bacteria in this fluid is crucial. It helps the clinicians to act in time in case of severe contamination and to prevent further complications.

There are three existent methods, which are used to perform a microbiological analysis on drain fluid [1]. The first method is bacteria culture, which determines the type of bacteria present in the drain fluid. A sample from the drain fluid is placed on a glass plate where known nutrients for a specific bacteria type are provided.

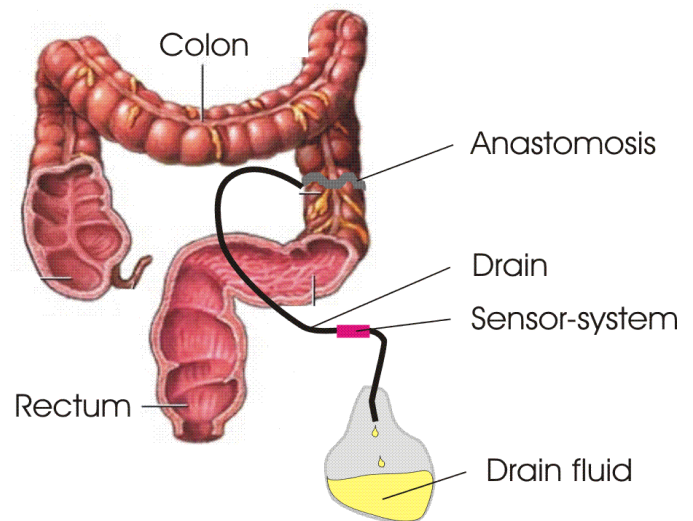


Figure 1. Drain fluid sensor system

If bacteria consume these nutrients and multiply, then the type of bacteria can be determined. Unfortunately, this method can only specify the type of bacteria and not the trend of bacterial growth. Furthermore, this method is time consuming, since it takes 24 hours to obtain the results.

The second method is Raman Spectroscopy, which is based on inelastic light scattering of a molecule. Raman scattering occurs with a change in vibrational, rotational or electronic energy of a molecule. The difference in energy between the incident photon and the Raman scattered photon is equal to the energy of a vibration of the molecule. A plot of intensity of scattered light versus energy difference is a Raman spectrum. Analyzing this spectrum of these photons identifies the molecules. Due to the high costs of the instrumentation, this method is an expensive diagnostic tool.

The third method is Polymerase Chain Reaction (PCR); this method is an enzymatic *in vitro* amplification of a piece of ‘target’ DNA [2]. Due to the high sensitivity of PCR, it is also sensitive to contamination errors, which can lead to unreliable results.

Due to the disadvantages of the methods presented above, the aim of this work is to fabricate a low cost measurement system, which can be used for monitoring the drain fluid,

bedside and directly.

II. METHOD

The ability to detect bacteria based on the absorption of near-infrared radiation in contaminated drain fluid has been investigated in a previous study [3]. Using a spectroscopic setup to measure absorption, a set of discrete wavelengths was found with strong contrast between contaminated and clear samples. In this work, only a single-wavelength is used with a photodiode, which is sensitive to this wavelength. Due to its low cost, the near-infrared sensor technique is a diagnostic technique with a large potential in the medical world.

The optical sensor system has to fulfill certain design requirements. The device should be insensitive to environmental perturbation sources (light, high-frequency devices, heat sources), portable, small and user-friendly. Therefore, the system that we built consists of an LED-driver, an LED (at 1900nm wavelength), a sample holder, a photodiode and read-out electronics. Figure 2 presents the block diagram of the measurement setup of the optical sensor-system.

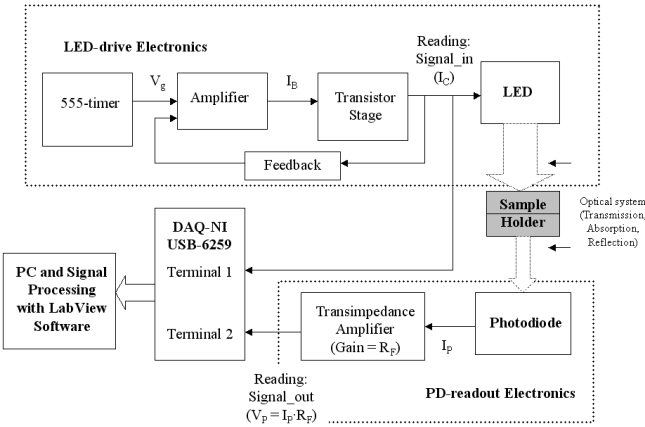


Figure 2. The block diagram of the measurement setup

The LED-driver electronics consists of a 555-timer, an amplifier, and an NPN bipolar transistor. The photodiode, which has responsivity of 100A/W at 1900nm is used to detect the transmitted light. For the photodiode-readout electronics a transimpedance amplifier is utilized to convert the photocurrent to a voltage. The gain of the system is determined by setting the feedback resistor of the amplifier to an appropriate value. The liquid to be investigated is placed in a sample holder, which is positioned in the middle of the optical path. This sample holder is composed of two glass plates, called beta cells and a spacer ring placed between them, to hold the liquid. Figure 3 presents a photo of the experimental measurement setup.

Two 5V regulators (positive and negative) for two 9Volt batteries supply the power of the sensor-system. A well-defined current is needed to drive the LED for stable output

intensity. The current is chosen based on the following factors: the thermal effect that may cause a decrease in intensity, power consumption of the system and the required sensitivity for the detection of the absorption by the sample.

The 555-timer generates voltage pulses, which operates in astable multivibrator mode to switches between two voltages. The frequency of the pulses and their duty cycle are set by the RC network values.

The generated pulse voltage is connected to an amplifier, which is used to create a constant relation with the voltage over the static emitter resistor of the transistor. This voltage causes a constant current through the LED. The data-acquisition hardware DAQ-NI USB-6259, monitors the LED current by measuring the voltage over the emitter resistor V_{R_E} , which has the following equation:

$$V_{R_E} = i_{LED} \cdot R_E \quad (1)$$

The obtain data is then sent to a PC and processed using LabView (National Instruments).

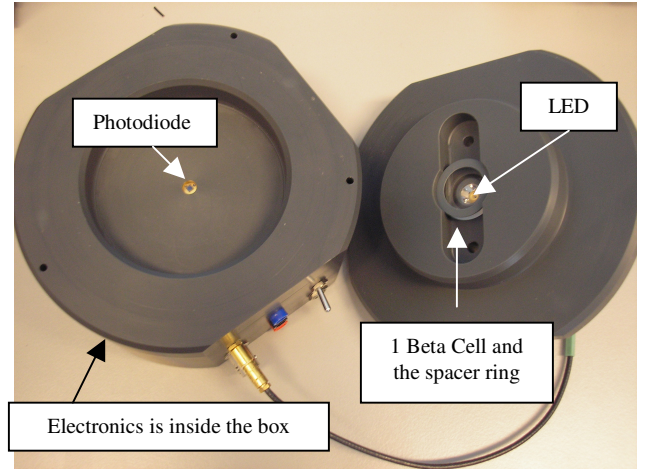


Figure 3. The experimental optical sensor-system

The relation between the optical power generated by the LED and the current flowing through it is [4]:

$$P_{source} = \left(\frac{i_{LED}}{e} \right) \eta_i h \nu \quad (2)$$

Where i_{LED} is the current through the LED, $e = 1.6022 \times 10^{-19} C$ is the elementary charge, $h = 6.63 \times 10^{-34}$ is the Planck's constant and ν is the frequency of the light wave. The η_i is the internal efficiency, which is also the electrical-to-optical conversion efficiency, which has the following relation [4]:

$$P_{source} \approx \eta_i P_{elec} \quad (3)$$

and

$$P_{elec} = i_{LED} \times V_F \quad (4)$$

Where $\frac{h\nu}{e} = \frac{E_g}{e} \approx v_f$, v_f is the forward voltage and E_g is the bandgap energy of the diode material.

Not all the electrical energy (P_{elec}) is converted to optical energy. The non-radiative mechanism causes the conversion of electrical energy to heat due to the vibration of the lattice atoms [5]. This temperature effect has an impact on the stability of the intensity. In order to minimize this temperature effect, a Quasi-Continuous Wave (Quasi-CW) of 20% duty cycle is chosen to drive the current through the LED. The modulated signal is driven by the 555-timer with a frequency of 400Hz. This frequency modulation is chosen to minimize the bandwidth requirements, while enabling effective suppression of low and high frequency perturbations.

The photons that are emitted by the LED propagate through an optical path, with the sample holder placed in the middle of it. The glass plates of the sample holder are made of CaF_2 and have a 95% transmission at 1900nm wavelength [6]. The thickness of one CaF_2 glass plate is 4mm; the ring spacer that is used is 0.5mm. Thus, the total optical path (including the mechanical holder in the box) has a length of 1.1cm.

Some of the optical energy that passes through this sample holder will reach the photodiode. The photodiode converts the optical light into a photocurrent, which is converted into a voltage by the transimpedance amplifier with a gain of $10^5 \Omega$. The voltage output is given by the following equation:

$$V_{\text{out}} = I_{\text{ph}} \times R_F \quad (5)$$

I_{ph} is the generated photocurrent and R_F is the feedback resistor. The responsivity, $\mathfrak{R} [A/W]$, of the detector output is given by the following formula [4]:

$$\mathfrak{R} = \frac{I_{\text{ph}}}{P_{\text{incident}}} \quad (6)$$

Where the I_{ph} is the generated photocurrent and P_{incident} is the optical power exiting the sample holder detected by the photodiode.

The incident optical power P_{incident} , which has passed through the sample with the thickness of length L will follow Beer's law of absorption:

$$P_{\text{incident}} = P_{\text{source}} e^{-\alpha L} \quad (7)$$

Where α is the absorption coefficient of the sample.

The power is proportional to the voltage output of the photodiode (V_{out}). The measured parameter of the system is the ratio between the output voltage, and the input voltage of the system (V_{out}/V_{R_E}). Combining equations (1)-(7), the following formula holds:

$$\frac{V_{\text{out}}}{V_{R_E}} = \eta_i \frac{R_F \mathfrak{R}}{R_E} V_f e^{-\alpha L} \quad (8)$$

The analog signals V_{out} and V_{R_E} are acquired using the data acquisition hardware and are subsequently subjected to digital signal processing in LabView.

III. MEASUREMENTS AND RESULTS

At first, measurements were performed to characterize the sensor system from a technical point of view. The LED and photodiode were tested without the drive- and read-out electronics. Instead, a current source was used to generate a constant current through the LED. The intensity of the LED was measured with the photodiode, by measuring the current through it as function of distance (Figure 4). The beam path was aligned, the components were shielded from the environment and the constant current through the LED was set to 100mA. Two values are given in the figure, the dot sign gives the first reading value when the LED was just turned on and the square sign gives the second value after the LED was 15 minutes on.

Although the generated photocurrent is highest at a distance of 4cm, the chosen optical path of the system is 1cm. It is necessary to take an optimal distance between the LED and photodiode to overcome optical losses due to reflection and absorption by surrounding materials.

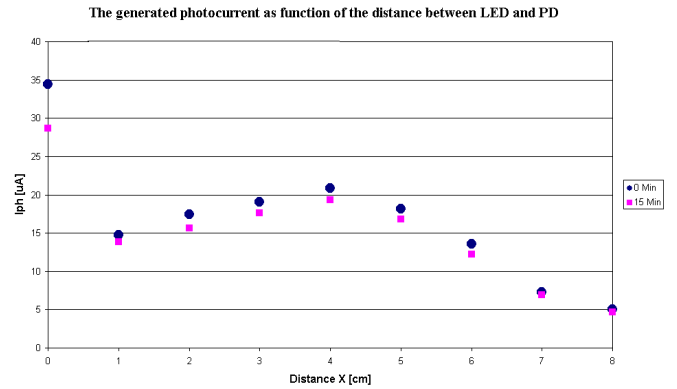


Figure 4. The generated photocurrent at different distances

The first series of tests, after the technical system characterization, was performed with salt solutions (Figure 5). There were 3 samples used with the following percentages: 5%, 10% and 15%. The measurement was conducted in a time span of 30 minutes and with a LED current of 180mA.

The equilibrium of water molecules is sensitive to the following factors: temperature changes, changes in concentrations of different electrolytes and changes in pH [7]. When salt is added to water, these factors will determine the transmission spectra of the solution. The result in Figure 5 shows the difference in transmission for different salt concentrations in water. The more salt is added, the higher the transmission due to the shift in the spectrum to higher transmission bands.

REFERENCES

- [1] N.Komen, R.W.F. Bruin, G.J. Kleinrensink, J.Jeekel, J.F. Lange, "Anastomotic leakage, the search for a reliable biomarker", *Accepted for publication in Diseases of Colon and Rectum*.
- [2] P.L. Stern and M.A. Stanley, "Human Papillomaviruses and Cervical Cancer: Biology and Immunology", Oxford University Press, Oxford, 1994; **48-50**.
- [3] M.P. Pakula, D. Tanase, K. Kraal, G. de Graaf, J.F. Lange, P.J. French, "Optical measurements on drain fluid for the detection of anastomotic leakage", *Proceedings of the 3rd Annual International IEEE EMBS Special Topic Conference on Microtechnologies in Medicine and Biology, Kahuku, Oahu, Hawaii, 12-15 May 2005*.
- [4] R.S. Quimby, "Photonics and lasers an introduction", Wiley-Interscience, New Jersey, 2006; **185**.
- [5] E. Fred Schubert, "Light Emitting Diodes, Second edition", Cambridge University Press, Cambridge, 2006; **35**.
- [6] <http://www.redoptronics.com/CaF2-optical-material.html>
- [7] H. Gremlich and B. Yan, "Infrared and Raman Spectroscopy of Biological Materials", Marcel Dekker, Inc., New York, 2001; **266**.

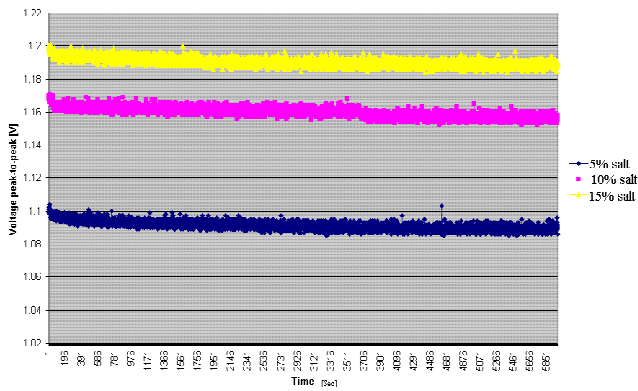


Figure 5. The NIR transmissions of salt dissolved in water

Another series of tests were performed using solutions containing different percentages of *Escherichia Coli* (E. Coli) bacteria. This bacteria is considered to be the most common bacteria present in the drain fluid, when leakage occurs. The samples were taken from the Erasmus Hospital, Laboratory of Bacteriology. The result gives the peak-to-peak of the output voltage (V_{out}) of two different samples (Figure 6). One sample has 0% contamination, and is considered to be clean and the second sample has 10% contamination and a lower transmission level than the clean sample. The measurement is conducted in a time span of 30 minutes and using a LED current of 180mA.

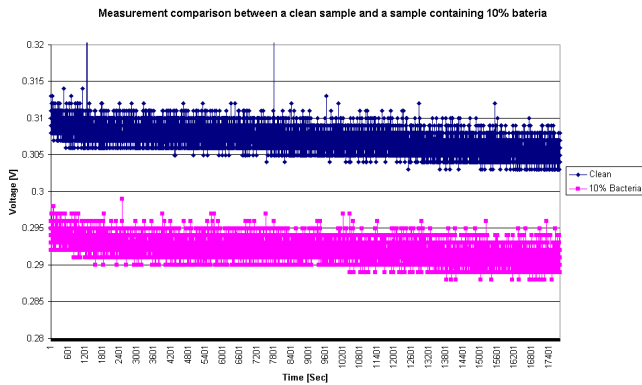


Figure 6. The NIR transmissions of bacteria solutions

IV. CONCLUSIONS

An optical sensor system to detect the presence of bacteria contamination in drain fluid was presented. A near-infrared LED and a photodiode are the basic components of this measurement system. Initial tests were performed to characterize the system. Another series of tests were performed with samples containing different percentages of salt and bacteria. From the obtained results, the ability to distinguish between the different concentrations of bacteria and salt solutions has been shown. Further experiments are necessary and currently in progress to gain more detailed information.