Smart Optical Wireless Sensor for Real Time Swimmers Feedback

Rabee M. Hagem¹, David V. Thiel¹, Steven G.

O'Keefe¹, Nicholas Dahm¹, Andy Stamm¹

¹Centre for Wireless Monitoring and Applications

Griffith University

Brisbane, Queensland, Australia,

r.hagem@griffith.edu.au

Thomas Fickenscher²

²Chair, High-Frequency Engineering, Helmut Schmidt University

University of the Federal Armed Forces
Hamburg, Germany

Abstract— Water is difficult environment for a wireless communications during swimming. A novel swimmer feedback system to enable consistent swimming pace consists of a ring of eight green LEDs which transmits information from a wrist mounted accelerometer using frequency shift keying (FSK) and on-off keying (OOK). The receiver on the goggles used an integrated detector preamplifier (IDP). The percentage of received optical data was determined for different positions for the swimmer's hand in different swimming styles (Freestyle, breaststroke, backstroke and butterfly). The system was evaluated in air and water to evaluate the preferred arm position and LED for communications. The stroke rate was determined using a 3-axis accelerometer and the interpretative firmware is different for each swimming style. One or more LEDs will be switched on during the cycle to achieve a maximum link performance. This system can be employed in pacing swimmers in both pool and open water swimming.

I. INTRODUCTION

Athlete monitoring using movement sensors can provide information to improve their performance. A swimmer usually generates a significant number of air bubbles during swimming. Recently the authors reported the effect of air bubbles on underwater optical communications [1]. The authors reported link budget calculations in order to choose suitable components for swimming applications [2]. The requirements for the device were wearability to prevent disturbance to normal swimming and more than 1m transmission distance (wrist to head). The data recorded should be processed at the transmitter and useful information sent to the receiver (eg. stroke rate, lap rate and swimming style). Most previous work was dependent on post processing for swim data in order to evaluate the swim performance [3-5]. The authors designed and implemented this low cost and short range optical wireless FSK modem [6].

II. RELATED WORK

There are many applications for underwater optical wireless communication. Transferring high data rate in a limited amount of time reduces the power consumption and this allows transmission of pictures and short video for reliable surveillance and monitoring. An important application of underwater optical wireless communication is pollution monitoring and data collection including water temperature, turbidity specific conductivity and oxygen concentration [7]. The point to point and diffused optical wireless communication literature is presented.

For the point-to-point optical wireless communication, IrDA protocols were used by replacing their transceivers with visible components such as the LEDs and the photodiodes. In [8] a low cost and low power underwater optical wireless communication system based on using the IrDA protocols with visible components was implemented. Also in [9] the IrDA protocols were used with 3 Watt LEDs in the green-blue visible light with a photodiode which is sensitive in the visible light spectrum. The low cost of hardware was minimized by eliminating high level error corrections and link management. A 2 m radius omnidirectional signal was achieved with five transmitters and with additional lenses, 5 m directional links were achieved underwater. In [10] and [11] a low cost, medium range underwater optical wireless communication system was achieved with a complex detection algorithm. Different experiments were done and the system achieved line of sight communication link (LOS) for 10 m with 310bps data rate. In [6] a LOS communications link achieved a distance of more than 1m underwater with 2.4kbps based on using frequency shift keying (FSK). In [12], [13] and [14] an optical wireless modem based on using IrDA protocols with high power LEDs was designed and implemented. This optical modem achieved LOS communications with 300kbps in a range less than 8 m.

For diffusive underwater optical wireless communications, some literature reported for different applications. In [15] a point-to-point communications link developed by Ambalux

[16] achieved omnidirectional communication based on using green-blue light. The system was tested in a pool and in a tank. The results of the experiments showed that the separation distance between the transmitter and the receiver, viewing angle and the water turbidity level all have a significant effect on the optical signal. They investigated the threshold viewing angle (TVA) which represents the minimum viewing angle at which the communication lost. They suggested two geometry models: icosahedrons and spherical hexagon and they found that the first was much better because of the simplicity in geometry and an ability to achieve omnidirectional coverage using the selected LEDs. In [17] an omni-directional system based on using six blue LEDs proposed. A 2π steradian hemisphere coverage area was achieved underwater for a range of 10 m. The receiver was a photomultiplier tube (PMT) chosen because of low noise, high speed and high sensitivity. This work was for underwater observation and the communication was between mobile autonomous underwater vehicle and a fixed nodes.

The optical wireless system presented in this paper will be used to give a real time feedback to swimmers about their performance and this will help them to adjust and improve their performance during training.

III. DESIGN CONSIDERATION

The design of an underwater optical wireless communication system considered different aspects such as: selection of transmission light sources including power, beamwidth and wavelength. The selection of a detector including sensitivity, field of view and quantum efficiency and an aiming and tracking strategy ensured success of the network [7]. In this paper a small and light system with low data rate was required. The power consumption was an important factor and this affected the choice of the modulation technique. To implement an efficient omnidirectional optical wireless communication system underwater, low cost and low power components were chosen. The LEDs at the transmitter were chosen and an (IDP) as a receiver because of the fast response. In the case of the omnidirectional optical wireless system design, several factors were noted [18]. Fig. 1 shows the optical wireless transmitter to cover a circular area without overlap.

Figure 1. Transmitter to cover a circular area without overlap [7].

Fig. 2 shows the optical wireless transmitter based on using LEDs to cover a circular area with overlap.

Figure 2. Transmitter to cover a circular area with overlap [7].

Assuming that n LEDs transmitters are placed at equal distance on a circular bracelet with a radius r and considering that the diameter of a transmitter is 2ρ . Therefore τ will be [7].

$$\tau = \frac{2\pi r - 2n\rho}{n} \quad (1)$$

The angular difference between two neighboring transmitters is given as [7].

$$\phi = 360^\circ \frac{\tau}{2\pi} \quad (2)$$

The coverage area A for a single transmitter is according to [18].

$$A = R^2 \tan(\theta) + 0.5\pi R \tan(\theta)^2 \quad (3)$$

There are two options to calculate the effective coverage area C for each LED as a single transmitter based on the value of φ , θ , r and R . The coverage area for a neighbor transmitter will not overlapping if

$$R \tan \theta \leq (R + r) \tan(0.5\varphi) \quad (4)$$

This will make $A=C$ which means that the effective area will be equal to the coverage area.

The second possibility will happen if a neighbor transmitter overlaps and this will be if

$$R \tan \theta > (R + r) \tan(0.5\varphi) \quad (5)$$

This will make the effective coverage area $C=A-I$ and I will be the interference or the overlap area. The good design for an omnidirection optical wireless system should avoid or minimize the interference area [7].

IV. SYSTEM DESIGN

An omnidirectional optical wireless system for swimmers feedback requires all the LEDs on the ring to transmit. In this case the interference and the overlap are not important. However, as some LEDs will not contribute to the link, excessive power is used. A smart optical wireless sensor might use a single LED which is activated once during the swim cycle. This needs a design which takes into consideration the overlap between the adjacent transmitters. In addition, there

are some factors which are important to consider in the design of an omnidirectional optical wireless system. These are diameter of the ring supporting LEDs, the field of view of the LEDs (FOV) and the number of the LEDs which depends on the (FOV) for the LEDs. Taking into account these design issues, an omnidirectional transmitter was designed and implemented based on using eight superflux green LED (L-7676CVGC-H) with 70° field of view (FOV) disposed on a circular ring of 7.62 cm diameter and length of 24 cm. A single integrated detector preamplifier receiver was used. The modulation technique used was frequency shift keying (FSK) and on-off keying (OOK). To generate the acceleration data, nCore 2.0 [19] was used at the transmitter and the receiver. Hardware and software modifications were required in order to connect this sensor to the optical wireless system. Experiments in air and water validated the optical wireless sensor and allowed an investigation of the smart sensor system. The maximum acceleration based on the swimmer's hand was converted to modulation suitable for the LED or LEDs that give the best communication link. Fig. 3 shows the electronics for the smart optical wireless feedback system showing the location of LED1 and by counting clockwise to access LED8. The LEDs ring was worn by a swimmer and LED1 was beneath the thumb.

Figure 3. The smart optical wireless system for real time swimmers feedback

V. EXPERIMENTAL DESIGN AND RESULTS

Experiments were undertaken in air and water to assess the smart sensor concept. The first experiment was conducted in water by attaching the optical transmitter with the LEDs ring to a swimmer's wrist and the receiver with the RGB LED to his /her head. Eight LEDs were used for the continuous light experiment because the overlap and the interference between the LEDs is not important when all the LEDs on.

The percentage time when the link was intact was measured for four different swim strokes when all LEDs were illuminated continuously. The results showed that the link was valid for 54.3% in freestyle, 60.3%, 45.25% and 50.5% in breaststroke, backstroke and butterfly respectively. Fig.4 shows the test situation for the smart optical wireless system for real time swimmers feedback.

Figure 4. Testing the smart optical wireless system for real time swimmers feedback

The second experiment investigated the effect of each LED on the received data. One LED was turned on each time and the swimmer was asked to swim. The percentage of received data was calculated. The main purpose of this experiment was to check which LEDs contribute to the received optical data. The next is based on turning different LEDs on throughout the stroke cycle depending on the arm position. This is determined from 3-axis accelerometer data. This experiment was repeated for all the LEDs and from the received optical data a conclusion was drawn about which LED or combination of the LEDs is better to use. Table I shows the percentage of the received data for different LEDs. From the table, it is clear that LED 4,5 and 6 have a big contribution on the received data. The position of these LEDs will be used for the smart sensor. The firm ware for the smart sensor was written in C and used to program the AVR microcontroller on the nCor2.0. The software finds the maximum acceleration on the y-axis and this was used to determine the stroke time.

TABLE I. PERCENTAGE OF RECEIVING OPTICAL DATA WITH TURNING ON DIFFERENT LEDs IN AIR

LEDs	Number of strokes	% Received data
LED1	22	4.5
LED2	20	25
LED3	20	25
LED4	20	55
LED5	21	33
LED6	20	95
LED7	19	0
LED8	20	20

VI. CONCLUSIONS

An optical wireless sensor system was designed and implemented using an omnidirectional transmitter and LEDs to give a real time feedback to help swimmers to improve their performance during training. FSK and OOK modulation

techniques were used. Two different experiments were done one in water and one in air. The first one which was done in water by using eight LEDs disposed on a circular ring with turning all the LEDs on. While eight LEDs were used in this experiment, five were sufficient for continuous communication. The percentage of receiving data was calculated for different swimming styles. The results showed that 54.3% was the received data in freestyle, while 60.3%, 45.25% and 50.5% was the percentage of receiving data in breaststroke, backstroke and butterfly respectively. The next experiment was conducted in air to investigate the percentage of received data for each LED individually in order to apply the smart sensor concept. Eight LEDs were used and one of them was switched on each time. The overlap was not important in this experiment. The results showed that LED 6 was the best with 95% received data, while LED5 was the next with 55% received data. The worst was LED7 with 0% received data. This means that the positions of LEDs 4,5 and 6 will be used for implementing the smart sensor concept. For future work five LEDs will be used on a ring and the smart sensor program will control which LED or combination of LEDs needed to turn on throughout the stroke cycle based on the arm position determined using 3-axis accelerometer data. Further work will include using data burst transmission which allows the optical transmitter to record data and burst it once when the link is open. This will save power and will increase the battery life.

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