Development of a Transcutaneous Optical Information Transmission System for Total Artificial Heart Using Near Infrared Laser

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Abstract

In the total artificial heart(TAH), a transcutaneous information transmission system(TITS) is very important to monitor the TAH status and detect the device failure, and repair the possible problems. First of all, the communication channel(skin) and method were simulated in terms of transmittance, scattering, reflection and absorption, then the system was designed with size reduction including low power consumption and reliability compared to the previous one. The informations are transmitted through the skin(approximately 1cm in depth) by frequency modulated near infrared(NIR) pulses using 780nm laser diodes as transmitters and photodiode as receiver with high speed and high spectral sensitivity. The logic high and low frequencies are 3MHz, 1MHz respectively. The system is a bidirectional data link for more than 38.4Kbps data rate, full-duplex with a bit error rate of less than 10^{-5}.

Introduction

The TAH developed by the Seoul National University is composed of a moving actuator, internal/external controller, battery unit, transcutaneous energy/information transmission(TEIT) system and total management unit. It uses a brushless DC motor as a moving actuator for blood pumping, microprocessor-based(Intel 87C196KD) internal controller for the actuator control, Li-ion battery for operating TAH system, transcutaneous energy transmission(TET) system for operating TAH and charging the internal battery, transcutaneous information transmission(TIT) system for transferring the data , and the DSP-based total management system for emergency control, battery management and TEIT processing. We can get lots of informations from the internal CPU and the DSP unit so that we can estimate the status of the TAH. So we need to get those data esternally and we also need to send the control messages to the TAH from outside to inside. In the development of a totally implantable artificial heart system, eliminating percutaneous wires or tubes is requisite in order to reduce the incidence of infection and allow tether free operation. The TEIT system is preferred over other alternatives because of its relative simplicity as well as acceptable performance [1].

Materials and Methods

1. Modeling the channel

The channel of this communication system is skin. At present, a rigorous theory is far from being available, partly because skin is irregularly shaped, has hair follicles and glands, is inhomogenious, multilayered, and has anisotropic physical properties. So any fruitful attempt to understand skin optics requires a considerably simplified model for the skin [2].

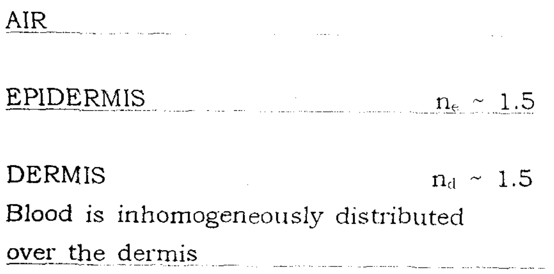

Fig. 1. Schematic model of skin with plane parallel epidermal and dermal layers.

Fig. 1. shows the simplified schematic model of skin consisting of epidermis and dermis as two plane parallel layers with isotropic physical properties. The layers are assumed to have the same refractive index($n \sim 1.37$-1.5) but a different number density of absorbers and scatterers that are randomly distributed over the volume [2].

Between about 300 and 1000nm nonpigmented tissues have scattering dominating over absorption. Under these circumstances the transport equation can be approximated by a diffusion equation. Under conditions of cylindrical symmetry the diffusion equation reads [2]

$$\left[\frac{d^2 \Phi_d(z,r)}{dz^2} + \frac{d^2 \Phi_d(z,r)}{dr^2} + \frac{1}{r}\frac{d \Phi_d(z,r)}{dr}\right]$$

$$-3\sigma_a[\sigma_a + \sigma_s(1-g)]\Phi_d(z,r) \qquad (1)$$

$$= -3\sigma_s[\sigma_s + (1+g)\sigma_a] I_c(z,r)$$

where $\Phi_d(z,r)$(watt/m^2) is the diffuse light fluence rate, defined as the total amount of diffuse light power that passes through a small sphere located at (z,r) divided by the cross sectional area of that sphere, $I_c(z,r)$(watt/m^2) is the source for the diffuse light distribution, and σ_a, σ_s, g are the absorption coefficient, scattering coefficient, anisotropy factor respectively. The total fluence rate is the sum of the collimated and the diffuse components [2]

$$\Phi(z,r) = \Phi_c(z,r) + \Phi_d(z,r) \qquad (2)$$

where $\Phi(z,r)$(watt/m^2) is the total fluence rate and $\Phi_c(z,r) = I_c(z,r)$; see, e.g., Ishimaru [3] and Groenhuis *et al* [4]. According to this model, the near infrared light has good transmitting characteristics through the skin over other wavelengt h range of light.

In the *In Vitro* test, the transmittance of the Near infrared light with 940nm in wavelength was examined using various thickness of porcine skins. The light emitter/receiver module is composed of 1 photodiode located at the ceter of 4 Infrared Emitting Diode(IED)s. As the light emitters, 4 IDEs(EL23F, Japan) having a peak emission wavelength of 940nm which is in the infrared light range are used. As a light receiver, a PIN type photodiode(HPI-2263, Japan) having a peak wavelength of 900nm is used. Fig.2 shows the relative optical signal level with respect to the emitting signal. In other words, the emitting signal level is the reference signal(optical signal level = 1) so that the received signal level is the relative level to the reference level (relative optical signal level = received signal / reference signal) [5].

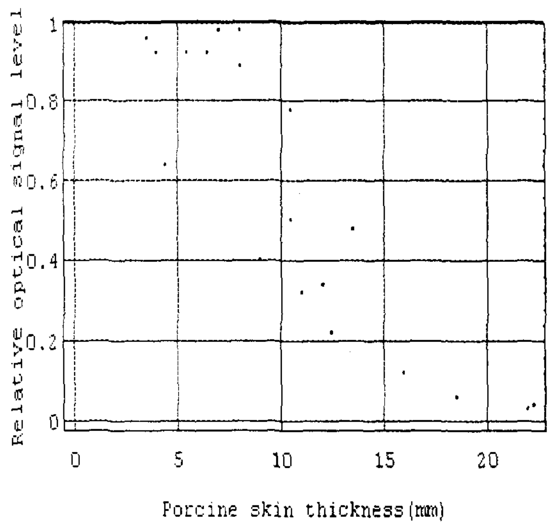

Fig. 2. Relative optical signal levels with respect to the various porcine skin thicknesses

2. System

In our TAH system, the TIT system will be implanted with the TET system. The TET coil has some space inside it, so the transmitters and the receiver will be located in that space. Fig. 3. shows the TIT system transmitter and receiver with TET coil. In that case, the received signals should be distinguised from the reflected signals. So we used the frequency modulation using different frequencies to distinguish the received and the reflected signals.

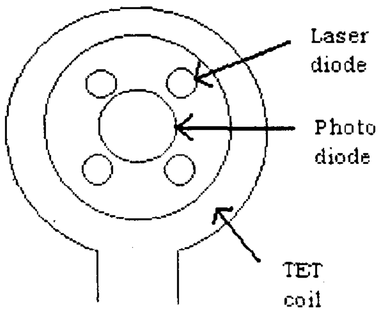

Fig. 3. TIT system transmitter/receiver arrangement with TET coil.

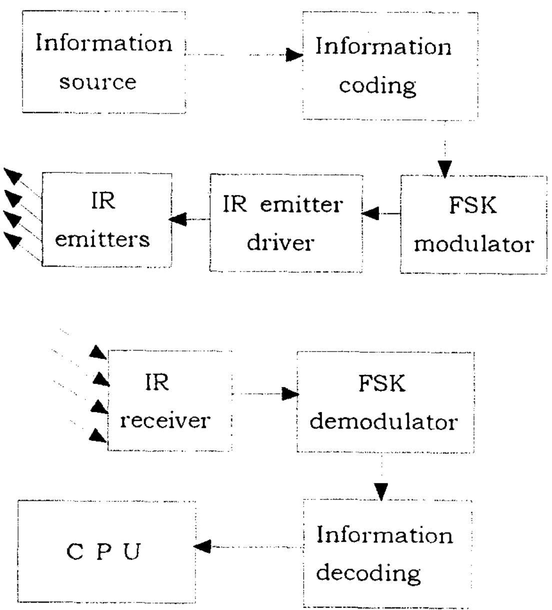

Fig. 4. Schematic block diagram of the TIT system.

The schematic block diagram of the TIT system is shown in Fig. 4. The transmitter consists of the modulation part, infrared light emitter driver, and the infrared light emitters and the receiver is composed of the infrared light detector, demdulation part. The TIT system contains the transmitter and the receiver units in pair so that it operates in the full-duplex way.

The modulation part modulates the logic 0, logic 1 signals with the 1MHz and 3MHz rectangular waves respectively. Through the driving part, the modulated signals switch the infrared light emitters. The 780nm infrared laser diodes(LT022MC, Sharp) are used as infrared light emitting devices, and the large area(41.3mm^2) photodiode(IPL10050, IPL) having a peak spectral response of 800nm is used as an infrared light receiver. The demodulation part demodulates the received signals to the original logic signals.

Results

In the TAH control, the communication speed between the internal controller and the external monitor CPU is now 38.4kbps. So the communication speed is now tuned to that speed but it can handle the faster communication speed. The bit error rate(BER) of the system should be less than 10^{-5}. In the *In Vitro* test (TIT system only), we could keep the BER less than 10^{-5}, so the system operated sufficiently well.

Conclusion

Roughly, the performance of the developed system was sufficient for the transcutaneous information transmission of the TAH. Through more *In vitro* and *In vivo* tests, the performance of the TIT system should be verified more strictly. We are searching for 880~950nm range laser diode which has good performance. So if we find one, the IR light emitter will be changed, and the IR light receiving photodiode will be changed to the large area(100mm^2) fast photediode (OSD100-6, Centronic). The developed TIT system didn't adopt the coding scheme yet. The DSP-based signal processing system is under developping. So afterwards, the linear block coding scheme will be adopted for error correction [6].

References

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