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Design of a telemetry system based on wireless power transmission for physiological parameter monitoring

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An implanted telemetry system for experimental animals with or without anaesthesia can be used to continuously monitor physiological parameters. This system is significant not only in the study of organisms but also in the evaluation of drug efficacy, artificial organs, and auxiliary devices. The system is composed of a miniature electronic capsule, a wireless power transmission module, a data-recording device, and a processing module. An electrocardiograph, a temperature sensor, and a pressure sensor are integrated in the miniature electronic capsule, in which the signals are transmitted in vitro by wireless communication after filtering, amplification, and A/D sampling. To overcome the power shortage of batteries, a wireless power transmission module based on electromagnetic induction was designed. The transmitting coil of a rectangular-section solenoid and a 3D receiving coil are proposed according to stability and safety constraints. Experiments show that at least 150 mW of power could pick up on the load in a volume of $\Phi 10.5 \text{ mm} \times 11 \text{ mm}$, with a transmission efficiency of 2.56%. Vivisection experiments verified the feasibility of the integrated radio-telemetry system. © 2015 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution 3.0 Unported License. [http://dx.doi.org/10.1063/1.4907170]

I. INTRODUCTION

Implantable telemetry is a practical technique to obtain physiological information on animals in free state during real-time and long-term experiments. This technique is highly important for auxiliary device, artificial organ, and drug efficacy evaluation. Physiological information includes electrocardiograph (ECG) signals, blood pressure, body temperature, and pulse, among others. Some improvements in the detection technology for these parameters have been achieved,\textsuperscript{1-3} mainly through the use of radio-telemetry. A mature-animal blood-pressure telemetry technology was presented.\textsuperscript{4} A temperature transmitter for temperature detection was proposed and improved.\textsuperscript{5} An implantable ECG telemetry system was developed.\textsuperscript{6} However, these devices are battery operated and thus cannot be used for long-term monitoring. Young-Ho Yoon et al.\textsuperscript{7} proposed a small ECG telemetry system that utilizes transcutaneous energy transmission (TET) technology and is powered by a rechargeable battery. However, the transmitting coil of the TET system must be fixed on the animal’s body, and the driven source is conductive. The animal is unable to remain in a free state, so the effects of these monitors are not ideal. In this situation, wireless power transmission technology based on electromagnetic induction becomes a feasible way to solve the energy problems in a radio-telemetry system.

The main challenges in applying wireless power transmission for a telemetry system that monitors physiological parameters are transmission stability and biological safety. Many studies have focused on improving transmission stability.\textsuperscript{8,9} The specific absorption rate (SAR) must also be
measured to evaluate biological safety. Measuring the incremental impedance of the primary coil is a feasible way to approximate the whole-body average SAR. The resolution of these two problems paved the way for the design of wireless power transmission systems. Unfortunately, unlike in the gastrointestinal (GI) tract, the primary coil of a telemetry system that monitors animal physiological parameters should expand its spatial extent to release the constraint on the active range of the animal. Meanwhile, physiological parameters suffer from a small electromagnetic interference from the coil. The corresponding stability and safety constraints in a telemetry system are therefore entirely different from those in the GI tract.

This study proposes an implantable telemetry system based on wireless power transmission to monitor animal physiological parameters, such as ECG signals, body temperature, and blood pressure, for real-time and long-term monitoring. This system could work with any animal position and pose in the coil.

II. SYSTEM OVERVIEW

Figure 1 shows that the proposed telemetry system consists of an implantable micro-electronic capsule, wireless energy supply modules, a wireless data recorder in vitro, and a PC data-processing software program.

The function modules focus on the head of the implantable microelectronic capsule, where sensors are integrated to record the ECG signals, body temperature, and blood pressure of the animals. These physiological parameters are first converted into electrical signals and then amplified by the operational amplifier of the high-precision and high common-mode rejection ratio. After AD conversion, these signals are sent in vitro via wireless communication, received by a data logger, displayed in real time, and saved onto a multimedia card. The information on animal ECG signals, body temperature, and blood pressure can be obtained from the saved data with the use of a PC data processing software program. The receiving sets of the wireless power transmission module are in the rear of the capsule, which triggers an electromotive force in the magnetic field induced by the transmitting coil and powers the telemetry system after rectification and regulation.

III. SIGNAL ACQUISITION AND MODULATION MODULE

The ECG signal is weak, low in frequency, and under a strong noise background. To filter the possible high-frequency noise, a passive filter circuit for high-frequency noise is used. The preamplifier should have high input impedance, a high common-mode rejection ratio, high gain, and low noise. Therefore, AD627 is selected. The possible low-frequency noise could lead to a baseline drift, so an
RC high-pass filter is designed to eliminate this noise. The signal is then amplified to a suitable range for processing by AD8603. The temperature sensor selects a thermistor as the temperature-sensing element and a non-balance electric bridge as the circuit. The pressure sensor is doused into the animal’s abdominal artery to measure the pressure signal, with normal saline as the medium. These two signals are also amplified by AD8603. The signals are amplified to a suitable range and then converted to digital signals by the AD converter LTC1860L. All the flow of acquisition and processing are illustrated in figure 2.

IV. WIRELESS POWER TRANSMISSION MODULE

The wireless energy supply module consists of two parts: the transmission part and the receiving part. The transmitting coil generates an alternating magnetic field. The receiving sets induce electromotive force and power the telemetry system after rectification and regulation. The animal’s posture and position change relative to the transmitting coil, resulting in an unstable power transmission. Uniform magnetic field and 3D receiving sets are proposed to resolve this problem. The transmitting coil is a solenoid with a rectangular cross-section, similar to an animal cage, in consideration of animal size. The power source of the telemetry system provides no less than 150 mW of power in a given receiving volume of $\Phi 10.5 \text{mm} \times 11 \text{mm}$ for any position and orientation in the work region.

In accordance with the power requirement, a wireless power transmission module that consists of a rectangular solenoid transmitting coil and a 3D receiving coil is proposed. The transmitting coil has a size of 450 mm $\times$ 350 mm $\times$ 150 mm and is constructed with 180 strands of AWG 38 enameled copper wire. The three coils are geometrically orthogonal to one another and wound on a common ferrite core. The core should be high-permeability MnZn ferrite R10K to increase the magnetic flux, and the winding wire should be Litz wire AWG44 to reduce skin effect and proximity effect losses in the coils.
V. EXPERIMENTS

New Zealand rabbits with a mass of 4.2 kg were used as subjects in the experiments to verify the power transmission module. In accordance with the results of Ref. 10, the transmitting coil has 32 turns. When the input current is 0.9 A, the receiving power at the centre of the cage (where the magnetic field is at a minimum) in different orientations is as illustrated in Figure 3. The maximum is approximately 155 mW and the corresponding efficiency is 2.56%. Therefore, the wireless power transmission module can provide energy of less than 150 mW to meet the energy requirements of the system in any state. Meanwhile, the incremental impedance is 1.08 Ω, which corresponds to a whole-body average SAR of 0.21 W/kg. This whole-body average SAR satisfies the safety standard of < 0.4 W/kg.11

The integrated implantable capsule is shown in Figure 4. The capsule has a cylindrical body and a size of Φ13 mm × 30.9 mm, and the catheter of the pressure sensor and two ECG electrodes are inserted into the head. The tip of the catheter is doused into the animal’s abdominal artery, while the two electrodes are implanted in the proximal and distal ends.

The entire telemetry system is illustrated in Figure 5. The driven circuit is integrated in the driven control box, which can tune the resonant circuit and regulate the input power. The receiving sets are integrated into the telemetry system and implanted into the bodies of the anaesthetized rabbits. The physiological parameters of the animals, such as ECG signals, body temperature, and pressure, are
monitored in the rabbits placed in the transmitting coil after the system is powered. All the signals are transmitted wirelessly, received, and then displayed on an LED monitor. Meanwhile, the information is saved on an SD card and processed in a PC. The body temperature obtained is 37.2 to 37.3 °C with a resolution of 0.1 °C. The pressure is 74 to 83 mmHg, with systolic and diastolic blood pressure standard deviations of 1.47 and 0.90 mmHg, respectively. Compared with the practical signal, the measurement error is within the allowable range, and the system meets the design requirements.

VI. CONCLUSION

A telemetry system based on a wireless power transmission system is developed and tested to monitor physiological parameters. The wireless power transmission module allows experimental animals without anaesthesia to be monitored during long-term experiments. Preliminary tests show that ECG signals, temperature, and blood pressure are accurately measured. However, the present experiments are performed on animals under anaesthesia. Further experiments should use animals without anaesthesia as subjects to test and improve the robustness and accuracy of the system. In this way, the wide application of the telemetry system for monitoring of physiological parameters can be improved.

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