WIRELESS CONTROL OF MICROPUMP SYSTEM USING FLEXIBLE CIRCUIT BOARD FOR IMPLANTABLE DRUG DELIVERY APPLICATIONS

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ABSTRACT

Wireless communication is an important and critical issue for the micropump system for implantable drug delivery applications. For satisfying different installation requirements, the flexible circuit board is much suitable for different outer shape. As such, this paper provides a wireless implantable micropump system by flexible printed circuit board (FPCB). For normal electronic circuit design, the FR4 glass epoxy is famous in printed circuit board (PCB). Nevertheless, these PCBs are not suitable for portable device and biological applications due to the irregular surface. Therefore, a FPCB is performed for flexible application and helps to shrink the system into portable device. The micropump mainly consists of a wireless communication circuit, an antenna and a piezoelectric peristaltic micropump driving circuit. The experimental results demonstrate that the FPCB based wireless control of micropump system can deliver fluid in rates of 20ml/hr to 120ml/hr. The experimental results show that this system has minimum deviation in 0.00083. FPCB has the advantage of light, thin, flexible and suitable for portable device and animal experiments applications.

Keyword: Micropump, Flexible Printed Circuit Board (FPCB), Wireless, Drug Delivery, Biomedical.

INTRODUCTION

Wireless controlled micropump system is necessary for the implantable and portable drug delivery system. Diabetes patients especially need the drug delivery system. Diabetes in many countries has become common disease in recent years. There are 366 million people with Diabetes in 2011, and the total value will be expected to rise up to 552 million in 2030[1]. Therefore, many experts have been put into a diabetes-related research. In clinical trials which prove that diabetes through good glucose control can indeed effectively prevent or delay the diabetic retina [2], kidney [3] and neuropathy [4] and other diseases occurrence. The commercially available biophysical sensing systems or biomedical systems are mostly off-line operating. These systems display information on their screen or sent the collected data to a host computer with cable connection. Thus most of them are not able to provide real-time information for giving help to the doctor. Furthermore, these systems are not friendly in their size, weight and price. In recent years, micro-electronic mechanical systems (MEMSs) technology brings great improvement to the biomedical sensors and instruments. The biosensors and biomedical systems become lighter, handier and portable by using the MEMSs technology. Flexible printed circuit (FPC) technology has the advantage of light, thin, flexible. The FPC technology also helps to shrink the biosensor and biomedical systems into portable devices. For the portable biomedical systems, wireless communication is another great benefit that a host (ex. PC) can download controlling parameters to portable devices and upload measured data from portable devices without physical connections.

This study presents a portable and wireless liquid delivery system which can be applied in liquid delivery. This system is working at 2.4 GHz which provides fast communication speed, lower power consumption and small antenna dimension. This system uses FPC as the circuit board which can make the system lighter and flexible. A PC based graphic user interface (GUI) is developed as a monitoring system. This software monitoring system can control and access multiple portable and wireless
liquid delivery systems through a radio frequency (RF) transceiver. For the application of diabetes medical treatment, doctors and patients can monitor the volume of insulin or drug efficiently in a portable device by using the GUI monitoring system.

**DEVICE FABRICATION**

The proposed micropump system consists of a wireless communication circuit, and a piezoelectric peristaltic micropump and the micropump driving circuit. The fabrication of wireless micropumps made by flexible printed circuit board (FPCB) and MEMS technologies can provide micro fluid delivery and satisfies the requirement of precise injection. The FPCB in addition to thin and lightweight has been the most important demands of protable electronic devices, the thin brought highly flexible is advantage. The micropumps can be classified by different actuating principles. They are electrostatic [5], piezoelectric [6,7], thermo-pneumatic [8], electromagnetic [9], shape memory alloy, polymer and thermal. Which have wildly applications such as microfluidic applications [10], drug delivery [11] and blood delivery [12]. The piezoelectric peristaltic micropumps are very applicable in the microfluidic delivery, which have simple structure and less power consumption.

**Structures of FPCB and wireless device**

RF transceiver of the drug delivery system is constructed by the FPCB instead of the traditional printed circuit board (PCB). The specification of the FPCB includes the 50-um-thick polyimide (PI) substrate and 12-um-thick copper as the conductor layer. The dielectric constant (εr) of PI is in the ranges of 3.4 to 3.6. MEMs process is used for making up the RF transceiver in a FPCB. The finished antenna of RF transceiver is 12mm × 35mm. Fig. 1 shows the RF transceiver is in the size of 47mm × 50mm.

![Figure 1: RF transceiver in flexible printed circuit board](image)

The flexible antenna is designed and simulated by the Ansoft HFSS (High Frequency Structure Simulator) and the optimized flexible antenna structure is shown in Fig. 2. The return loss of antenna affects RF transmission quality. Higher return loss decrease both the transmission power and transmission distance of an antenna. The antenna return loss of the FPCB RF transceiver is measured by the network analyzer. Fig. 3 shows that the designed has -16.9dB return loss at 2.45GHz.
The peristaltic micropump consist three chambers and three actuators. An actuator is the most important part of a micro pump which provides the driving force to fluid. The actuators in the micropump comprise a 0.19-mm bulk PZT chip (T107-H4E-602, Piezo Systems, Inc.), 20-µm-thick silver epoxy (SYP-LBS), and a glass membrane with an area of 9 mm × 9 mm [13]. The screen printing technique is applied to coat the silver epoxy onto the glass membrane. Three PZT actuators are installed on the substrate and combined with the upper plate. The upper plate and substrate are poly(methyl methacrylate) (PMMA). Micro-wedge channels and chambers are produced via a micro-fabrication method. The wedge channels are 80 µm wide on the inlet side, 266 µm wide on the outlet side, 80 µm high, and 3.04 mm long. The chambers have a diameter of 7 mm and a depth of 15 µm. Fig. 4 shows the finished peristaltic micropump.
Fig. 4 Photograph of peristaltic micropump for the experiment of fluid delivery. The micropump size is 14 mm × 53 mm.

MATERIALS AND METHODS

The experimental system includes a graphical user interface (GUI) on computer, a flexible RF transceiver, a peristaltic micropump and its’ driving board and two storage tank. Also, a digital storage oscilloscope (DSO) and a network analyzer is use for signal analysis and data collection. This study develops a simple GUI for drug delivery system monitoring on a PC. The drug delivery system is controlled by GUI on RF communication. The micro-controller unit (MCU) of the drug delivery system receives instructions from GUI system and then drives the micropump to deliver the drug. For the peristaltic micropump control, the MCU outputs a 4-phase [12] driving signal in 37.5Hz. The driving circuit then boosts the driving signal up to 200Vpp for piezoelectric-based peristaltic micropump driving. A DSO displays and records the high voltage driving signal and sensing signal. The peristaltic micropump calculates output flow rate by counting the driving pulses of 4-phases driving sequence. For verifying the output flow rate of this system, the output liquid is measured by a high-precision scale liquid meter. A high precision liquid meter is in 0.1mg accuracy and ± 0.1mg of repeatability. Fig. 5 shows block diagram of the experimental platform. The experimental setup is shown in Fig. 6.

RESULTS AND DISCUSSION
In this study, an experimental platform is constructed for wireless drug delivery system control. The monitoring system through antenna of transceiver transmission control command. The impedance of transmission line and the antenna is advanced to 50Ω by matching circuit. The optimized transmission line can minimize the power reflected, and obtains the maximum power output.

For the portable and flexible application, the FPCB is first tested in different bending angle. The measured results of return loss in different bending angle are from -18.7dB to -12.8dB, respectively. Fig. 7 shows the experimental results. The experimental results illustrate that return loss is a function of the bending angle of FPCB.

![Fig. 7 Results of frequency response of the flexural FPCB antenna](image)

For the drug delivery experiment of this study, flow rate was set from 20 ml/hr to 120 ml/hr, in 20 ml/hr increment. The drug delivery system is control and monitored through wireless communication by GUI. Each flow rate setting is tested for ten times. The results of target flow and averaged output flow rates are shown in Fig. 8. The output flow rate is controlled in high accuracy and the deviation to target flow rate are around 0.00083% to 0.02%. Table 1 shows the experiment results. Hence, the control flow rate by wireless is feasible. Nevertheless, the future application of microfluidic flow rate controlling might require higher accuracy and resolution. Therefore, developing a new experimental platform and method to improve the flow rate control is needed.
Fig. 8 Experimental results of output flow rate

<table>
<thead>
<tr>
<th>Target flow rate (ml/hr)</th>
<th>20 ml/hr</th>
<th>40 ml/hr</th>
<th>60 ml/hr</th>
<th>80 ml/hr</th>
<th>100 ml/hr</th>
<th>120 ml/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output flow rate (ml/hr)</td>
<td>20.004</td>
<td>40.004</td>
<td>60.003</td>
<td>79.999</td>
<td>100.002</td>
<td>119.999</td>
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<tr>
<td>Deviation (%)</td>
<td>0.02</td>
<td>0.01</td>
<td>0.005</td>
<td>0.00125</td>
<td>0.002</td>
<td>0.00083</td>
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Table 1 Output flow rates and total deviation.

CONCLUSIONS
This study presents a wireless control of micropump system using flexible circuit board for implantable drug delivery application. FPCB provides the advantage of light, thin, flexible. The wireless transceiver of this system is suitable for the curved application. The flexible RF transceiver has good performance in both flat and curved environment. The bended RF transceiver has the return loss as low as -18.7dB. The test bending angle from 150° to 30° with 30° descending and the RF transceiver works properly. The wireless controlled peristaltic micropump successfully controls the output flow in high accuracy. The experimental results show that this system has minimum deviation in 0.00083. Therefore, this system is suitable in drug delivery especially in insulin delivery. The selected 2.4GHz frequency provides fast communication speed, lower power consumption and small antenna dimension. The FPCB can make the system lighter and flexible. In future research, the device can be further used for animal experiments and medical-related research and development.

REFERENCES
