Utilizing optical technique to develop an intelligent bio-chip monitoring system

YU-JEN PAN*, WIN-JET LUO[a]
Department of Computer and Communication Engineering, Ta Hwa Institute of Technology, Hsinchu, Taiwan, 307
[a]Department of Refrigeration, Air Conditioning and Energy Engineering, National Chin-Yi University of Technology, Taichung, Taiwan, 411

This study proposes utilizing optical method to build a monitoring system for bio-chip in wireless sensor network environment. We utilize the sensor network to study two practical applications for micro-device. One is novel operation process for the analysis of flow control in microfluidic devices. The other is investigation of possibility of generating high resolution chemical image. Both methods used optical technique to detect the liquid sample of bio-chip. This remote monitoring system can be adapted for other devices, as well as other vital sign measurements. It represents the first step in developing a ubiquitous sensing platform for telemedicine and remote monitoring.

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1. Introduction

Recent advances in the field of Microsystems have made possible the miniaturization of microfluidic systems on a microchip to carry out analytical analytes. Current devices monitoring instrumentation and practices can be restrictive. For example, in the mixing process, mixed samples degree monitoring can be monitored continuously with CCD (charge-coupled device) camera. This is an external detection camera to detect the mixing and collection the data in specific computer. The limitations of this are that the accuracy is highly variable. On the other hand, in computer use efficiency, due to the detection system is use wire equipment to set in traditional condition, the computer can only collect single data every time. A simple and cost effective solution is to utilize implantable microsystems utilizing wireless telemetry, which could increase monitoring efficiency by minimizing staff work load, increasing the amount of data obtained, and streamlining its storage and processing.

Wireless connectivity is going to offer the next evolutionary development step in the biomedical signals monitoring applications such as wireless sensor network [1]. A wireless sensor network is a wireless network consisting of autonomous sensor to monitor the physical or environmental conditions, such as temperature, sound, vibration or pressure, at different locations [2-4]. There are many proposed researches allowing the Wireless sensor network (WSN) to select adjacent sensor nodes to transmit commands and data by complex wireless communication protocols [5, 6]. But with such system, hardware implementation will become more difficult and costs will rise. Although there are many WSN researchers who propose quick and low complexity algorisms for the wireless communication between sensor nodes, they still assume high power consumption for data processing and solving timing and handshake problems. The applications for WSN are many and varied application. They are used in commercial and industrial application to monitor data that would be difficult or expensive to monitor using wired sensors. Typical applications of WSN include monitoring, tracking, and controlling. It is scattered in a region where it is meant to collect data through its sensor nodes.

Electroosmotic flow (EOF) requires no mechanical moving parts and enables the precise manipulation of very small sample volumes via the use of an appropriate voltage control scheme [7, 8]. Sequential injection analysis (SIA) is an alternative technique from flow injection analysis (FIA) that is commonly used in analytical chemistry. Sequential injection has been generally used in large-scale systems. SIA is used to provide a more complex analysis. It commonly operates with more than two reagents and without reconfiguring the device [9]. The sequential injection technique has been used in microfluidic devices for biochemical analysis. For example, Pu and Liu designed a microchip-based electroosmotic flow pump equipped with a six-way selection valve in a capillary-based SIA system for enzyme inhibition analysis [10]. Du et al. performed micorfluidic sequential injection by capillary force in micro-scale devices [11].

Chemical imaging system such as Light Addressable Potentiometric Sensor (LAPS) is an important tool to visualise the 2-D distribution of the chemical species on a

sensor chip [12, 13]. The conventional approach to generate chemical image by LAPS is to scan the chip by single modulated laser spot with X-Y stage. However, it suffers from bulky and slow measurement speed. Recently, digital light processing technology (DLP) was used to LAPS set-up [14] to simplify the set-up of light source. Nevertheless, this technique uses ARM-based processor to access internal digital micro-mirror device (DMD)-control, which is relatively complex for most users. The current study proposes an intelligent detection system that utilizing the WSN collects the necessary physical signals of a sensor. It is demonstrated qualitatively that the wireless sensor network can be used for collecting the necessary physical signals of the microfluidic device.

2. Method

2.1 Generation of discrete sample

In we previous research, a useful methodology of sequential injection had been proposed [15]. The sample plug flow can be produced by electrokinetically pre-focusing and switching, and then guided to the desired outlet port by means of a simple control voltage model. The results show that a microfluidic device is capable not only of generating a single length plug sample flow to a specified output port, but is also able to generate a series of different length plug samples. In this study, we utilize experimental result to demonstrate that the methodology is useful. Distance line (D-line) of methodology is designed to control the length of buffer flow. When D-line increases, the time (delay time) of the sample flow from channel-b to channel-a increases. Fig. 1 shows the injection channel contains two sample plugs (designated as plug A and plug B, respectively) separated by a quantity of buffer solution. Clearly, the length of the buffer solution is determined by the delay time, while the lengths of the two sample plugs depend on the times for which the respective outlet reservoirs are grounded. The symbol α designates the combined length of plug A and buffer, while β is for plug B and buffer. The traditional experiment setup of microfluidic device is presented in the literature [16]. The electrokinetic driving force was generated using a computer-controlled high-voltage power supply.

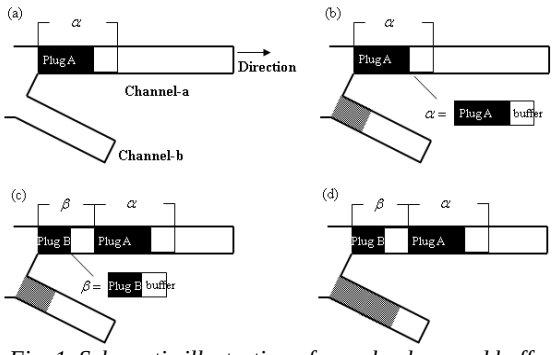


Fig. 1. Schematic illustration of sample plugs and buffer solution in injection channels.

2.2 Generation of chemical image

In this work, we demonstrate an amorphous-Si based LAPS structure and a commercially available projector as light source to generate the chemical image with high resolution. The schematic block diagram of the experimental set-up is shown in Fig. 2(a). The size, shape, movement, and modulation frequency of the light spot can be generated by the projector with computer-aided control. An objective lens of 50x is used to focus the light beam from the projector and the square shaped spot of size 50x50 μm is used for experiment. The atomic layer deposition technique (ALD) was used to deposit 10 nm HfO_2 on a-Si/ITO/glass substrate as sensing membrane (Fig. 2(b)).

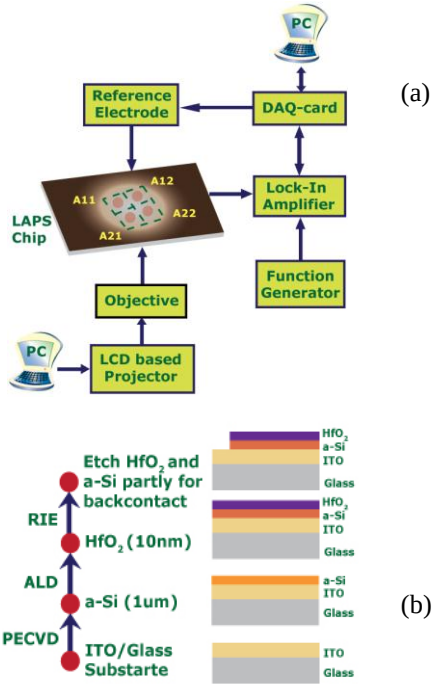


Fig. 2. (a) Block diagram of the experimental set-up with LCD projector as light source; (b) Process flow and cross-sectional view of a-Si based LAPS chip.

2.3 Framework of WSN

An overview of the steps in setting up an IEEE 802.15.4 based network is provided in Fig. 3. Once the network has been created by the coordinator, the end devices are allowed to join the network by performing Active Scan. In data transmission, the direct transmission is used to transfer the data from the end device to the coordinator. An End Device always sends a data frame directly to the Personal Area Network (PAN) coordinator. Once it has received the data, the coordinator may send an acknowledgement to the end device.

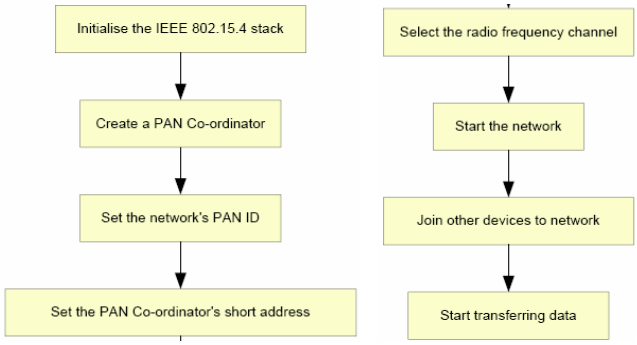


Fig. 3. Network set-up process.

3. Results and discussion

For development an intelligent microfluidic monitoring system, we design and set-up a wireless senor network system with Graphics User Interface (GUI)-based management to achieve this objective. The wireless sensor network is comprised of a PAN coordinator, routers and end devices. This study uses ZigBee wireless technology to develop the wireless sensor network. ZigBee is based on IEEE 802.15.4 wireless protocol, which focuses on sensor networks, control and home-care related applications. Fig.4 presents a schematic diagram of WSN framework. The CCD captured the data from microfluidic device, and then computer operates analysis process. The experimental data can show in computer or deliver to embeded control system by ZigBee wireless technology. Users can obtain the specific data and show in mobile device by wire/wireless environment.

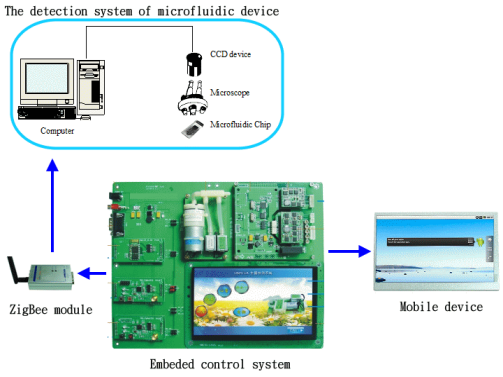


Fig. 4. Overall system schematic illustration of an intelligent microfluidic monitoring platform.

During the injection procedure, Distance line (D-line) is designed to introduce a quantity of buffer between successive discrete sample plugs in order to ensure that diffusive mixing does not take place between them in transportation process. As discussed previously, the length of the D-line is instrumental in determining the length of the buffer between successive sample plugs in the injection channel. Fig. 5 presents the result for the influence of D-line on production plug sample. As shown in Fig. 5(a), the plug samples are unable to separate entirely in channel-a. However, as shown in Fig. 5(b), under the same operating conditions, the introduction of a D-line, and hence permitting sufficient buffer to flow into channel-a between two successive samples. In the discrete injection process, it is necessary that different plugs are fully dispensed into the designated reservoirs. As discussed previously, the length of the sample plug introduced into channel-a can be controlled simply by regulating the time for which reservoir is grounded. In Fig. 6(a-c), concentration field determined through fluorescence imaging are shown over a complete injection cycle. Further, the performance of the discrete injection process is demonstrated in determination of fluorescent dye intensity (see Fig. 6(d)). The result show that the discrete injection procedure can be performed cyclically and continuously once the appropriate operating conditions have been specified and set up.

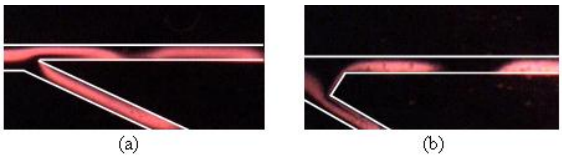


Fig. 5. Experimental results for the influence of D-line on producing discrete plug sample.

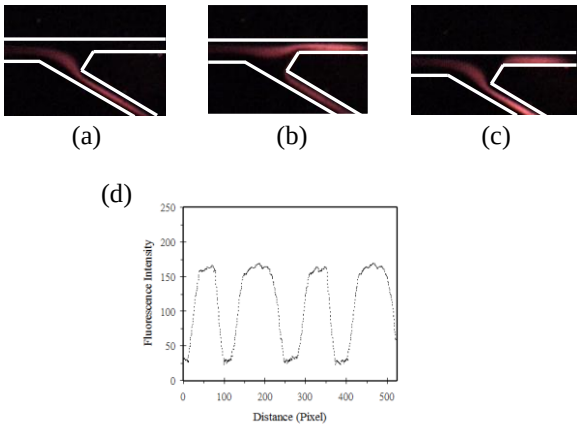


Fig. 6. Experimental results (a-c) of electrokinetically pre-foucsed micro flow switches producing plug sample in the channel-a. The recording (d) of two discrete plug samples showed the repeatability of the injection system.

For a chemical image generation process, a buffer solution is used as test solution. Fig. 7 shows that buffer solutions from pH 2 to 10 were successfully detected by using the projector set-up LAPS. The different spot position and the variation of photo-response at each point in 5x5 array are also investigated and shown in Fig. 8. The maximum variation among these points is calculated to be

2.88%. The variation of detection signal may be caused by non-uniform intensity of light source or uniformity distribution of a-si or HfO_2 layer. With further solving the uniformity problem, the proposed set-up would be a promising tool for generating chemical image conveniently.

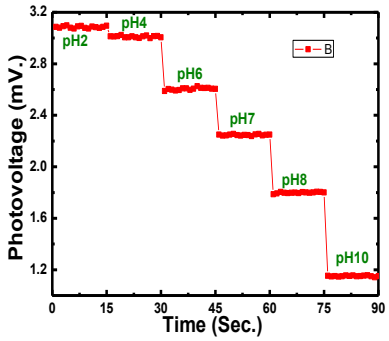
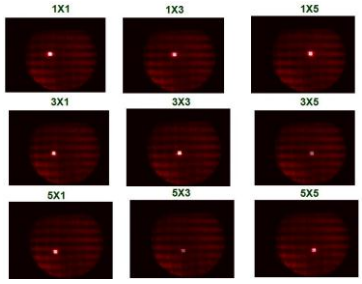


Fig. 7. LAPS chip response to different pH solution at constant bias 0.56 volt.

(a)



(b)

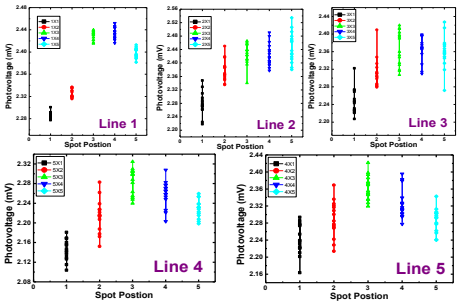


Fig. 8. (a) Differnet spot position during 5X5 array measurement. (b) Photoresponse variation at different spot of each line of 5 x 5 array for pH 7 solution at constant bias 0.56 volt.

4. Conclusion

We have demonstrated a wireless sensor network to collect the data of the bio-chip. The experimental results of a novel microfluidic manipulation technology shows that we previous research is practicability. Utilizing flow switching technique generates discrete sample to achieve continuous sequence sample traveling. Beside, we use light-addressable potentiometric sensor to generate high resolution chemical image. Buffer solutions from pH 2 to 10 were successfully detected by using commercial projector as light source. This study integrates wireless and optical technology into traditional detection system of bio-chip. The system can record the necessary signal data continuously and stores the data in a remote database. Researcher can use wireless network and mobile device to obtain practical data in anywhere.

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*Corresponding author: yjpan@thit.edu.tw