Automatic Bio-MEMS Smart Drug Delivery System

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Abstract

Traditional medicine injection is done by medical professionals. Patients need to see doctors or nurses for medicine injection. This brings inconvenience for the patients and increases the cost of medical care. Many senior patients with chronical diseases may need to inject multiple medicines everyday. Remembering the sequence of what medicine to inject at what time is not an easy job. Some medicine (such as insulin for diabetic patients) need to be delivered with precise dosage control according to the patient's real-time need. Manual injection by rough estimation may lead to under-dose or overdose. All these made the medicine delivery a complicated and challenging task. In this research, a smart drug delivery system which can automatically inject the medicines according to preprogrammed sequence is proposed. It consists of a micropump, micro drug reservoirs and microneedle array integrated with a smart control circuitry. It can deliver multiple medicines with precise dosage control and proper timing. It allows the patients to injection medicine anytime anywhere automatically without human interference. It makes the medicine injection a worry-free process. The proposed smart drug delivery system leads to improved efficiency and it is expected to bring revolutionary change to the current medicine delivery technology.

Introduction

Traditional drug delivery is generally achieved by manual injection with needles and syringes. Patients cannot do it by themselves and they need to see doctors or professional nurses for medicine injection. It brings inconvenience to the patients' travel plan and poses burden for the doctors/nurses. Furthermore, senior patients or patients with complicated health conditions may need to inject multiple medicines on a daily basis. Remembering the right time for the right medicine is never an easy job. Some medicines need to be injected according to the patient's real-time need. For example, diabetic patients need to inject insulin based on the fluctuation of their blood sugar levels. Traditional manual injection based on rough estimation easily lead to under-dose or over-dose, both of which are unhealthy to the patients. As a result, smart, safe and accurate drug delivery systems are in great demand and may bring revolutionary change to the current medicine delivery process.

In this research, a smart drug delivery system powered by Bio-MEMS (Bio-Microelectromechanical Systems) technology is proposed. It can automatically deliver multiple medicines according to pre-programmed sequence. It can also mix multiple medicines as needed and deliver medicine at certain rate. When it delivers medicine (such as insulin) on demand, it can automatically regulate the medicine delivery based on the signals from biosensors (e.g. glucose sensor) using a real-time feedback control system. Such a smart drug delivery system (SDDS) makes drug delivery process worry-free for the patients. It brings great convenience to patient's life and help reduce the burden for medical professionals. Combined with BioMEMS Lab-on-a-Chip technology, eventually patients can diagnosis the disease and do the treatment at home by themselves. This will bring revolutionary change to the current pattern of disease diagnosis and treatment.

Design Architecture of Smart Drug Delivery System (SDDS)

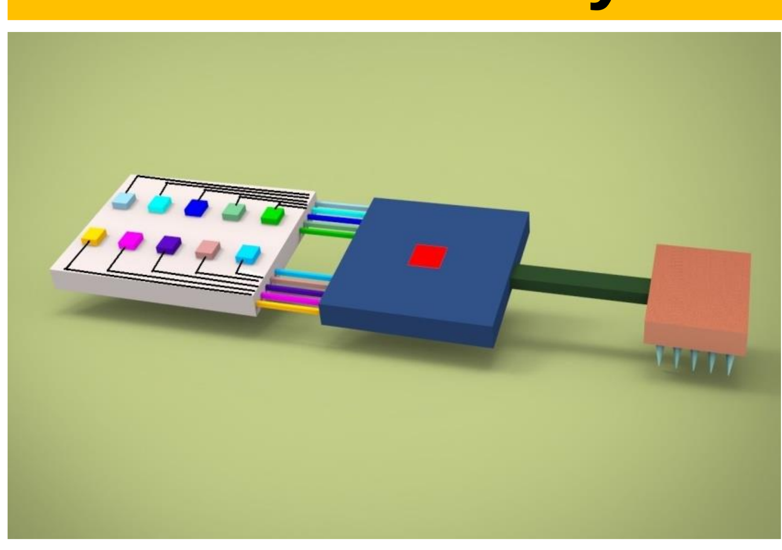

Figure 1: Complete smart drug delivery system (drug reservoir, micropump, microneedles)

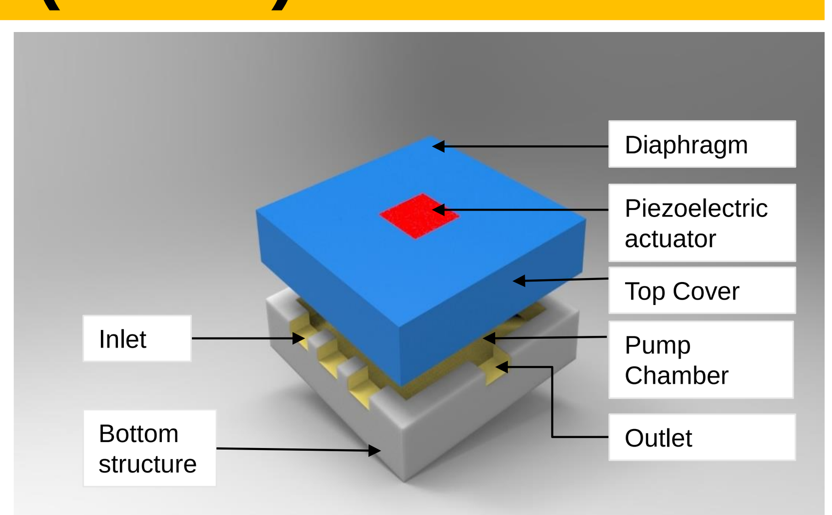

Figure 2: Multi-Input Single-Output (MIMO) Micropump used in smart drug delivery system

The structure diagram of the proposed Smart Drug Delivery System (SDDS) is shown in Figure 1. A Multi-Input Single-Output (MISO) micropump is used to pump the medicine, as shown in figure 2. The proposed SSDS consists of multiple drug reservoirs connected to the inlets of a piezoelectric MISO micropump. The single outlet of the micropump is connected to a microneedle array, which is always connected to the human skin like a patch. The MISO has seven inlets (six inlets for medicines and one inlet for flushing water) and each inlet has an active microvalve. Each microvalve can be individually controlled. If the microvalve is turned on, the corresponding medicine will be pumped into pump chamber and delivered into human body. The outlet valve is a one-way passive valve. It allows the medicine to be pumped out of the chamber toward the needle array, but not in the reverse direction.

Features of Smart Drug Delivery System

The following functional features are incorporated with the SDDS system:

1. Individual drug delivery with timing: Individual drug can be delivered according to preset timing schedule (e.g. medicine #2 can be delivered at 8pm everyday).

2. Mixing function: The micropump can mix two or more medicines as needed and deliver the mixed drug inside human body.

3. Medicine residual flushing**:** Flushing the pump chamber and microchannels with water to clear residues after each delivery of medicine.

4. Feedback control for certain drug delivery: For example, insulin delivery should be controlled by feedback signal from glucose sensor. If sensed glucose level < healthy level (using comparator), then insulin delivery should be stopped.

5. Emergency stop function: The SDDS should immediately stop the drug delivery in case a device failure is detected or suspected. For example, in case of a glucose sensor failure, it may give a wrong glucose level even a large amount of insulin is delivered. To ensure patient's safety, insulin should be immediately stopped and alarm should be triggered to alert the user about possible device failure.

6. Heating of certain medicine: Certain medicine may need to be heated to certain temperature for injection. Temperature sensor is needed to monitor the temperature of medicine being heated and feedback control is needed to achieve the target temperature of the medicine.

7. Incorporation of sensed health conditions of the patient (e.g. heart beat rate, blood pressure) from health monitoring device (e.g. Apple iwatch) to better help in the drug delivery process.

Results and Discussions

The block diagrams of the SDDS and its control circuitry is shown in Figures 3 and 4 respectively. The control circuitry coordinates the functions of the SDDS. It is programmable and doctors can preset the medicine delivery sequence according to the prescription. The 3D model of the SDDS is shown in Figure 5. The key design parameters of the SDDS is listed in Table 1.

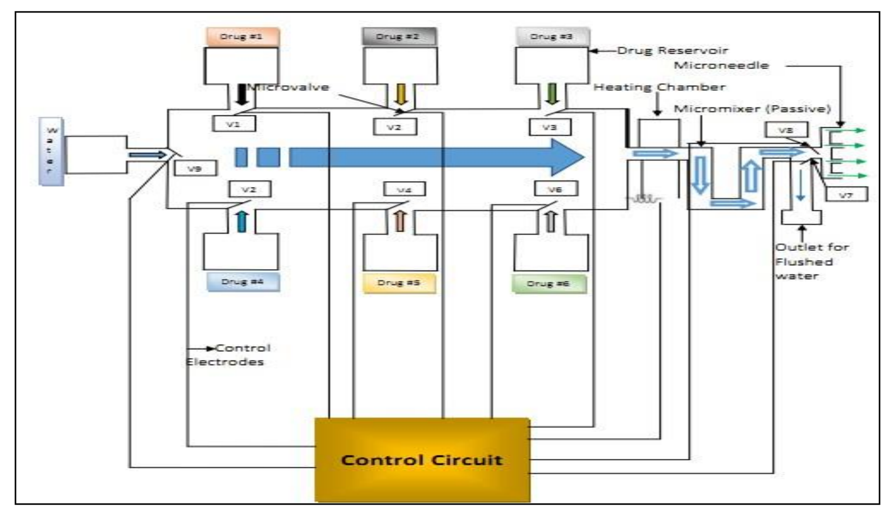

Figure 3: Block diagram of SDDS

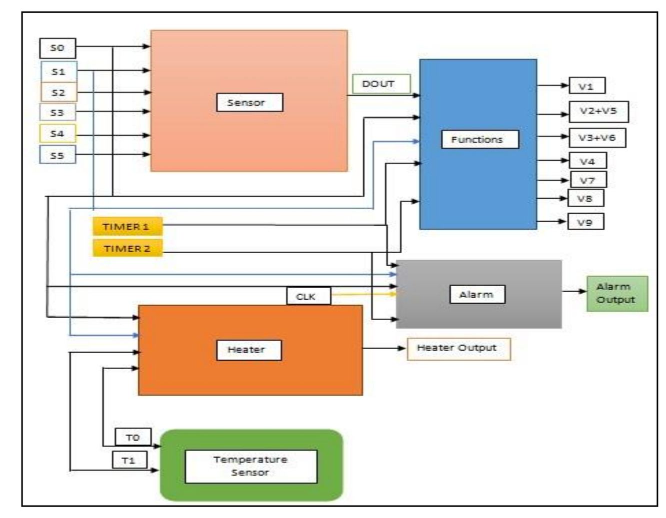

Figure 4: Block diagram of Control circuitry

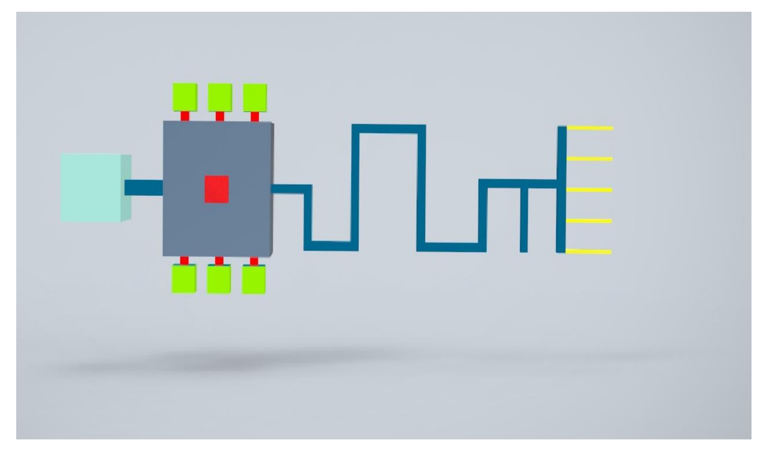

Figure 5: 3D model of SDDS

Table 1: Proposed MISO Micropump Parameters

Design Variables	Values (Unit: μm)
Length of the Water Reservoir	10000
Width of the Water Reservoir	10000
Length of the Water Reservoir Channel	4000
Width of the Water Reservoir Channel	2000
Length of the Pump Chamber	16000
Width of the Pump Chamber	16000
Length of the Micro Drug Reservoir	4000
Width of the Micro Drug Reservoir	4000
Length of the Micro Drug Reservoir Channel	1500
Width of the Micro Drug Reservoir Channel	1000
Length of the Micro-needdle	4000
Width of the Micro-needdle	500

The control circuit is simulated in PSPICE to verify its functions in several case-studies. The results are shown in Figs 6 and 7 respectively. As shown in figures, if there is any high heart beat rate, high blood pressure or any sign of allergy, the medicine injection will be paused to prevent over-burden to the human body.

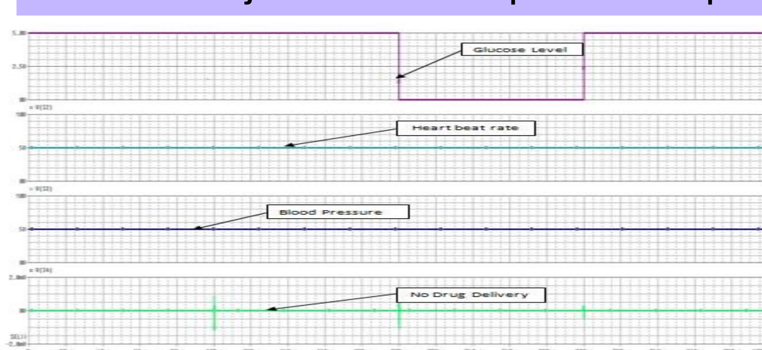

Figure 6: Drug delivery is disabled if patient has high heart beat rate, high blood pressure

Figure 7: Drug delivery is disabled if patient has any sign of allergy

Figure 8 shows the mixing and injection of two medicines into human body as needed. The valves for Drugs #2 and #3 are turned on, but the valves for all other drugs are turned off. Both medicines are pumped into the chamber, mixed and then delivered to he microneedle array. Figure 9 shows that if there is any error signal, it immediately turns off the medicine delivery process to protect the patient till finally the error alarm is removed.

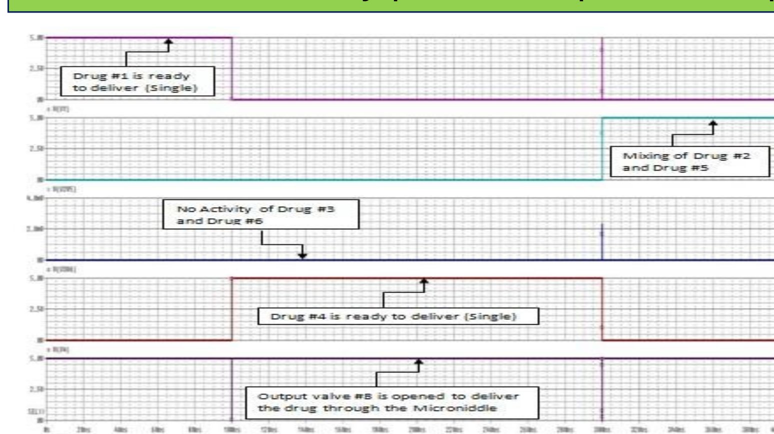

Figure 8: Drug mixing and delivery (drug #2 and #3 are mixed in micrpump chamber and delivered)

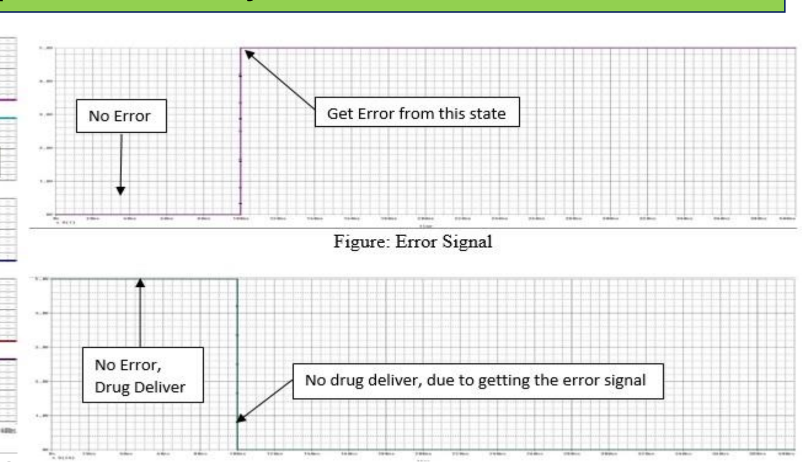

Figure 9: Drug delivery is turned off when any error signal is triggered

A water-flush function is also incorporated in the SDDS to clean the micropump and microchannels from any medicine residue after each medicine delivery process. This insures there is no medicine cross-contamination between two consecutive medicine delivery.

COMSOL simulation is used to verify the microfluid behavior of the medicines in the SDDS. The simulation results are shown in Figures 10-14 for different cases.

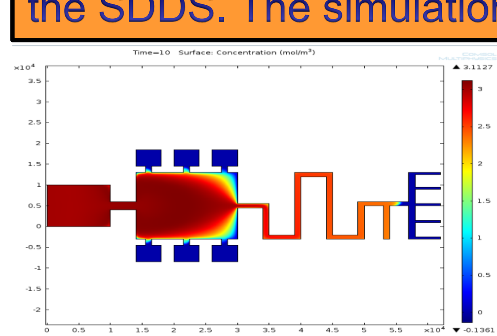

Figure 10: Concentration of Water (for flushing)

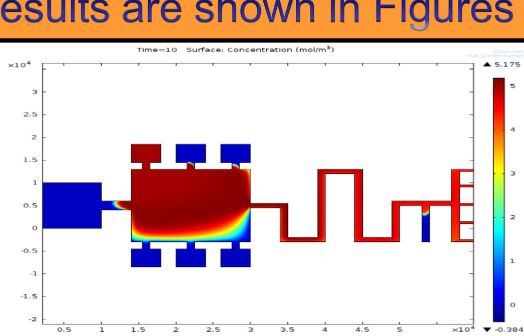

Figure 11: Concentration of Drug #1

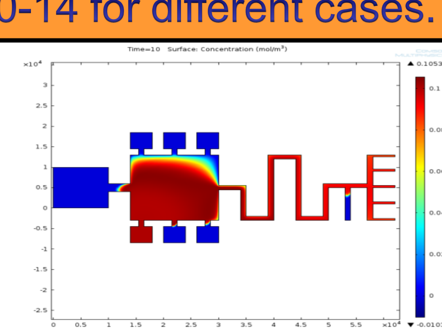

Figure 12: Concentration of Drug #4

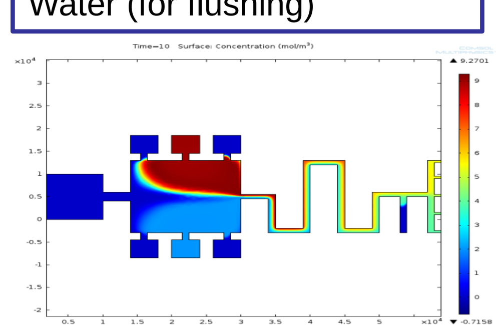

Figure 13: Concentration plot: drug #2 and #5 mixing

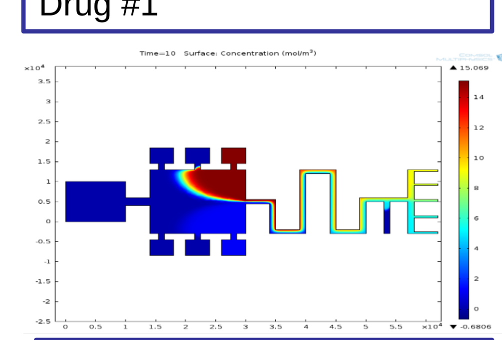

Figure 14: Concentration plot: mixing of drug #3 & #6

Different medicines with different concentrations are represented by different colors. Clean water is used for flushing operation.

Conclusion

In this poster, a smart and programmable multi-drug delivery system based on Bio-MEMS technology is proposed. It can automatically deliver multiple medicines according to pre-programmed sequence. It can also deliver medicine according to patient's real-time need following the sensed bio-signal (e.g. insulin delivery based on glucose sensing). Patients can use it for drug delivery at home or during travel. It makes medicine delivery a worry-free process and may bring revolutionary change to the current medicine delivery process.