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Design of Compact PCR Device based on Host-local Structure

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Abstract. We design a compact PCR device based on the host-local structure. The PCR device receives operation commands from the smart phone and sends operation results to the smart phone through Bluetooth communication. The implemented PCR device significantly reduces volume size of existing commercial PCR devices with a similar performance.

Keywords: PCR Device, Bluetooth, Host-local Structure, DNA Amplification

1 Introduction

DNA amplification is a process of producing multiple copies of a sequence of DNA. PCR(Polymerase Chain Reaction) is the most common DNA amplification method [1]. The proposed PCR structure minimizes the volume size and the implementation cost in order to support portability. The proposed structure supports only the PCR function but not the user interface function to minimize the volume size and the implementation cost. In the proposed structure, the user interface function is eliminated by exploiting the user interface function of smart phones via Bluetooth wireless communication. In this paper, we design and implement a firmware for micro-controller of PCR devices so that the PCR device would satisfy the following three requirements: receiving/sending the input/output from/to smart phones through wireless communication, the minimal volume size and low implementation cost, and reliable PCR function.

To evaluate working reliability of the designed PCR device, we construct a prototype PCR device with PIC18F4550 micro-controller chip. Compared with a commercial PCR device, the prototype PCR device reduces the volume size by 6/7 while maintaining the DNA amplification performance similarly.

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2 Proposed PCR Design

Fig. 1 shows the configuration of hardware components that are controlled by a micro-controller and perform temperature changes for PCR protocols. The plastic in the top of the figure is the cover of this device. The sensor below the plastic measures the temperature data of chamber and transfers it to the micro-controller. The coil heater increases the temperature of chamber and the aluminum spreads the heat evenly. The chamber contains DNA fragments being amplified and reagents triggering PCR operation. The Peltier below the chamber absorbs or produces heats according to the flow direction of electric current. The heater sink and the fan in the bottom of the figure help the absorbed heat to emit outside.

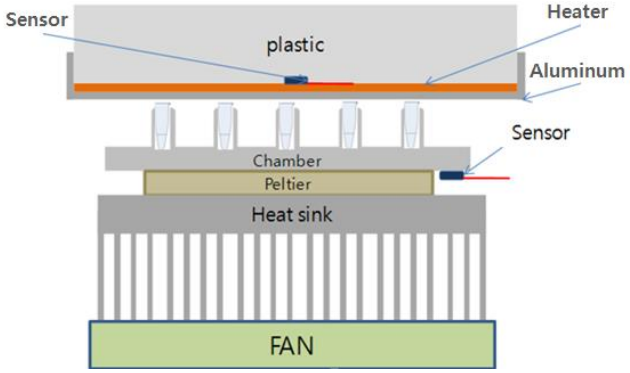

Fig. 1. Configuration of hardware components

The proposed PCR device employs the host-local structure [2,3]. In the host-local structure, the system management functions such as UI functions and file handling functions are moved to an existing computing system, called *host system*. The newly manufactured system, called *local system*, possesses only basic functions except the system management functions. The host-local model has two main benefits. One is to conserve human and time resources by eliminating the implementation of the system management functions into the local system. The other is to reduce the volume size and the implementation cost of the local system. In this paper, a smart phone plays a role of the host system and we design a new device that plays a role of the local system. The newly manufactured system performs the PCR protocol and communicates with the smart phone via Bluetooth.

Utilizing GUI (graphic user interface) on a smart phone, a user inputs a PCR protocol that holds temperature changes and their number of repetitions. The protocol is transferred to the firmware running on a micro-controller through Bluetooth wireless communication. After completely receiving the PCR protocol, the firmware starts to perform the temperature transitions in the PCR protocol. The firmware generates control signals of heating or cooling the Peltier component according to the temperature transitions in the PCR protocol. Meanwhile, the firmware collects the temperature data measured by sensors periodically. Based on the collected temperature data, the firmware determines the heating strength and the cooling strength to reach the target temperature of each transition of the PCR protocol. To

display the processing status of the PCR protocol to users, the information of the current step of temperature transition, the progressed time, the current measured temperature, etc. is transferred to the smartphone application through Bluetooth wireless communication.

The firmware receives a message and sends its response message periodically. We determine the period empirically. In our experiments, the maximum turn around delay is smaller than 200ms. This implies that the maximum delay of one-way communication is smaller than 100ms. Hence the firmware checks messages arrived from the host system per 100 msec. Also, if a message for the host system is ready, the firmware sends the message per 100 msec. In contrast, the host system checks the arrived messages and sends a message to the local system with a different period. If the period for the host system is equal to that for the local system, messages are possibly lost even when the wireless connection is established, due to synchronization problem. The period for the host system is determined to be 200 msec. The display image updated every 200 msec. causes negligible inconvenience for users.

The host system and the local system have the same size of messages with 32 bytes. The former 8 bytes are used for commands information in the host system and processing status information in the local system. The rest 23 bytes are used to hold debugging information.

3 Evaluation

For comparison of practical benefits, we construct a prototype PCR device in which the micro-controller is connected to the hardware components explained in Section 2. The constructed PCR device is compared with the existing commercial PCR product, MyGene PCR of the LongGene corporation, which is known as the smallest one with the lowest price among commercial PCR products. The volume of the constructed PCR device is width 11.5cm × length 13.6cm ×height 19cm = 2,971.6. The volume of the existing PCR product is width 24cm × length 31.5cm ×height 27.5cm = 20,790. The volume ratio of the constructed PCR device to the existing smallest PCR product is about 1/7.

Fig. 2 shows the results of DNA amplification performed by the constructed PCR device and the existing commercial PCR product. The DNA amplification results are analyzed using the same electrophoresis device and gel documentation system. In Fig. 2, the left part shows the analyzed image of the existing commercial device, and the center part shows that for the constructed device. The two analyzed images are almost equal, which implies that their DNA amplification performances are almost equal. The right part in Fig. 2 shows that the constructed PCR device does not amplify DNA fragments when the sample does not contain the target DNA fragments. The detailed analysis is addressed in our previous study [4].

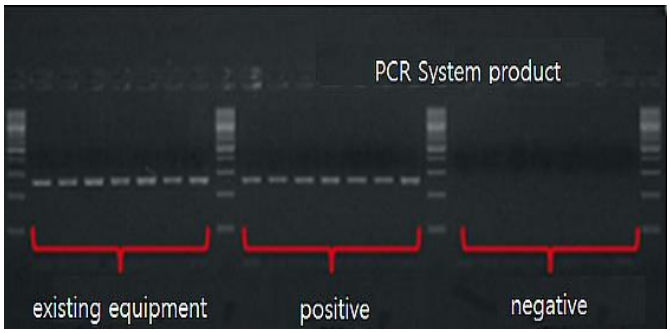

Fig. 2. Results of PCR amplification

4 Conclusions

We design a compact PCR device that is controlled by a smart phone through unstable Bluetooth wireless communication. Evaluation results shows that the constructed prototype device enhances portability by significantly reducing the volume size with a similar performance of DNA amplification, compared with existing commercial PCR products.

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