DIRECT ON-DISK WIRELESS TEMPERATURE MEASUREMENT FOR CENTRIFUGAL MICROFLUIDIC PLATFORMS

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ABSTRACT

For the first time we present an on-disk wireless temperature measurement system (Fig. 1) for centrifugal microfluidic platforms [1]. **Tiny thermistors with a volume of 54 nl** allow the direct **temperature measurement in almost any of cavity** (Fig. 2) of microfluidic chips with a resolution of 0.1 K. A rotating radio module transfers digitalized data to a stationary receiver with D/A converter being connected to a temperature controller. The total response time of the temperature measurement system is 9.6 ms. The rotating electronic elements are powered by inductive coupling with up to 2 W. The **radio transmission of sensor data** can be parameterized by any commercial PC via USB port. This system enables to precisely measure the temperature of fluids in centrifugal microfluidic systems and hence allows closed-loop control of direct heating systems e.g. IR radiators for fast Polymerase Chain Reaction (PCR) thermocycling processes.

KEYWORDS: Lab-on-a-Chip, Microfluidic, PCR, Thermocycling, wireless temperature measurement

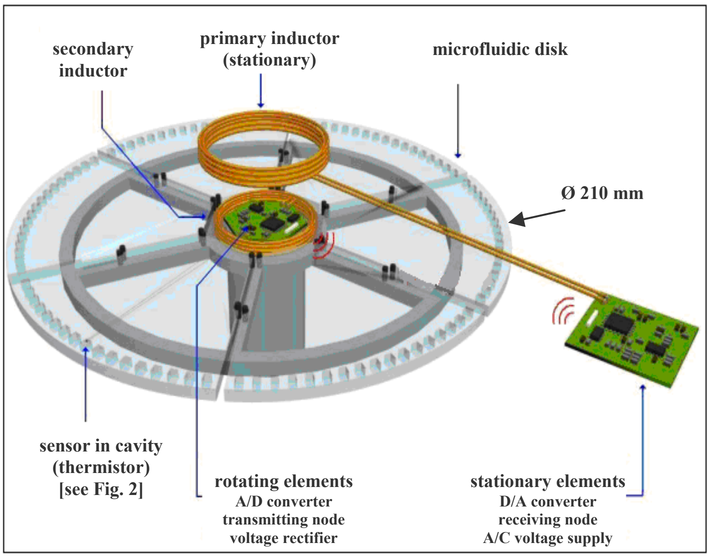

Fig. 1: Wireless temperature measurement system consisting of rotating and stationary elements.

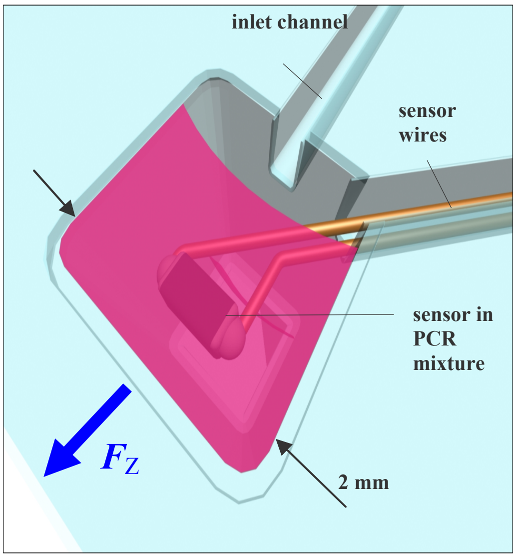

Fig. 2: Sensor positioned in cavity filled with 6 µl of PCR mixture (red) - depicted under rotation with F_z *as centrifugal force exhibiting a rather flat liquid-air interface.*

SYSTEM COMPOSITION

As temperature sensor a NTC (negative temperature coefficient) thermistor from Murata Electronics North America [2] is used. This SMD sensor with dimensions of 0.6 x 0.3 x 0.3 mm³ is bonded with isolated copper wires of 50 µm core diameter and connected to an A/D converter [3]. Voltage signals in the range of 270 mV – 1500 mV are converted to digital signals with a resolution of 10 bit at a sampling frequency of 200 kHz. The digital signal is transmitted wirelessly by a 2.45 GHz transceiver to a stationary receiving node with a data rate of 100 Hz. Both the transmitting and receiving nodes use MSP430 microcontrollers [3] and CC2500 radio transceivers [4]. Now the signal is D/A converted [5] and scaled to the standardized 0-10 V temperature controller interface [6]. The power signal of 12 VAC is provided by the half-bridge self-oscillating MOSFET driver IR21531 [7] via a primary copper coil with ~60 mm diameter by inductive coupling at near-resonant frequency of ~90 kHz to a secondary copper coil of similar diameter fixed on the rotating carrier. Processed by the voltage rectifier LP2980 [8] a controlled voltage signal of 3.3 VDC finally powers both the rotating transmitting node and the sensor connected to the A/D converter. These modules are arranged in a centrifugal test rig (Fig. 3) allowing the precise and fast thermocycling of fluids in microfluidic polymer film disks by tempered air and/or IR radiation.

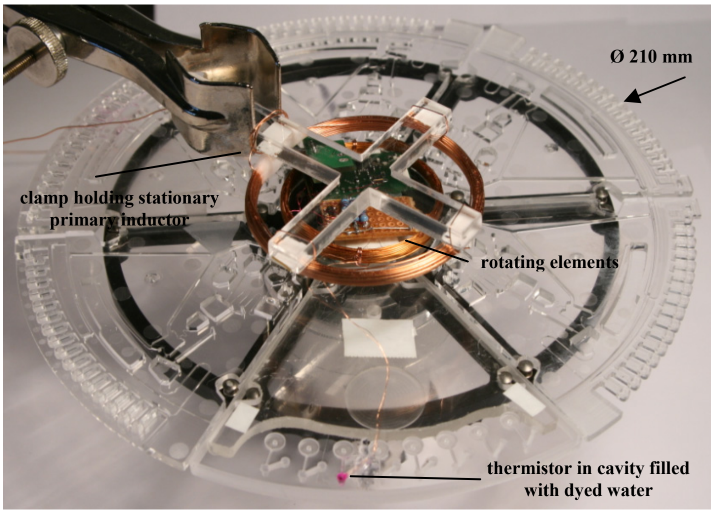

Fig. 3: Setup with thermistor, A/D converter, transmitting node, primary and secondary coils

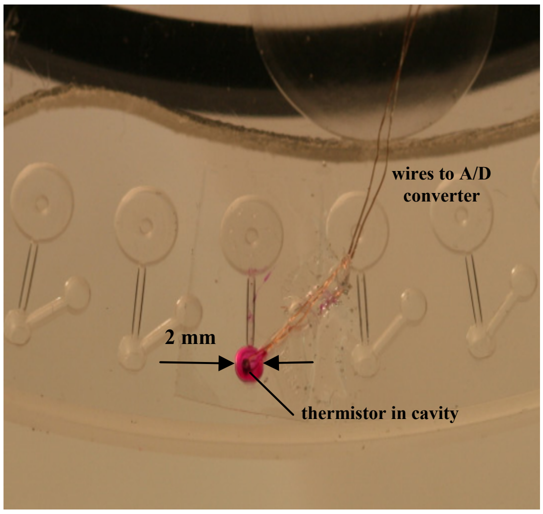

Fig. 4: NTC-thermistor fixed in a sealed PCR reaction chamber of a polymer film disk

EXPERIMENTAL RESULTS

The wireless data transmission has proven to be resistant to frequencies of rotation up to 30 Hz (Fig. 5). Average reception rates of 85 % combined with a data transfer algorithm repeating transfers up to 6 times at 2.45 GHz ensure a total reception rate of far more than 99 %. The voltage temperature characteristic of the thermistor (Fig. 6) does not show any hysteresis and the slightly non-linear response is linearized by a look-up table for the standardized 0-10 V controller interface. The delay of approximately 9.6 ms between the thermistor and the temperature controller input signal (Fig. 7) is small compared to the response time of the heating system (Fig. 8). Thermistors can be placed in any cavity of rotating disks, the vertical and horizontal position should consider the liquid-air interface under rotation (Fig. 2). The thermal capacity of the thermistor in comparison to the fluid in the reaction chamber should be very small in order to avoid any significant influence of the tempering process. A volume ratio of ~ 1:100 (54 nl (thermistor) / 6 µl (PCR mixture in cavity)) in our setup fully meets this demand. First thermocycling experiments demonstrate complete heating and cooling cycles (Fig. 8).

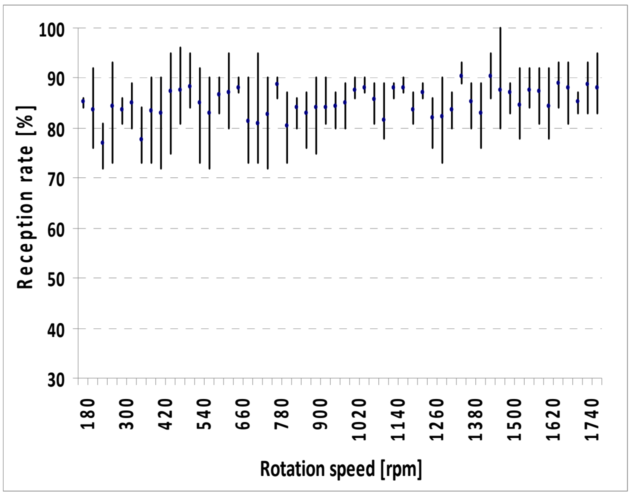

Fig. 5: Wireless data transmission during rotation

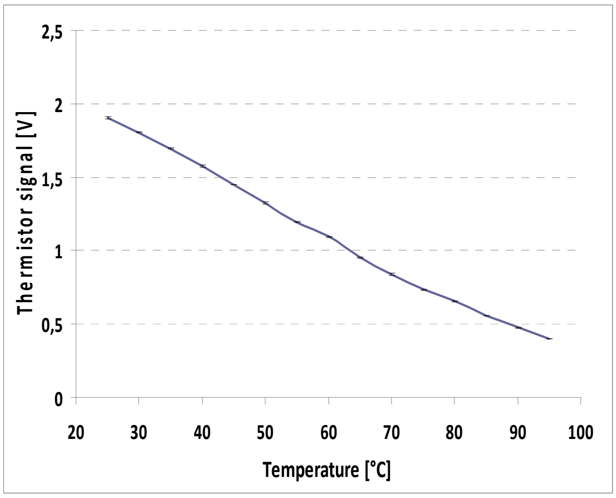

Fig. 6: Voltage temperature characteristic of thermistor

CONCLUSION

Direct **temperature measurement of fluids** in centrifugal microfluidic systems **at rotation frequencies of up to 30 Hz** increases both, the temperature control speed and precision of the temperature. It is allowing the **quick implementation of versatile temperature protocols with closed-loop control** for any cavity positions and volumes. Further it enables the **fast optimization of powerful direct heating systems** as IR radiators/diodes. Hence it creates new potentials in miniaturizing centrifugal microfluidic analyzers while enhancing their performance and accuracy.

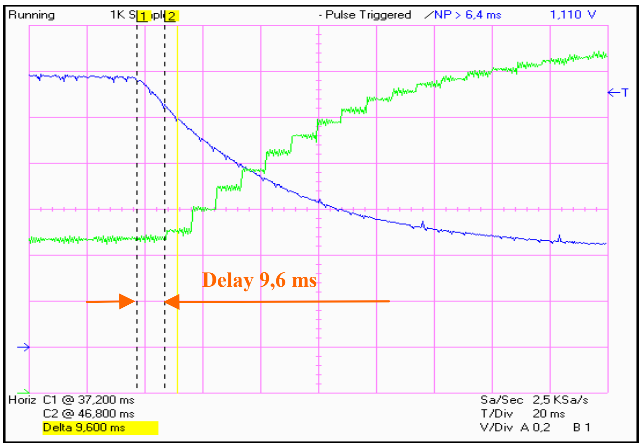

Fig. 7: Step response of thermistor (blue) and transmitted D/A converted signal (green) after 50 K step

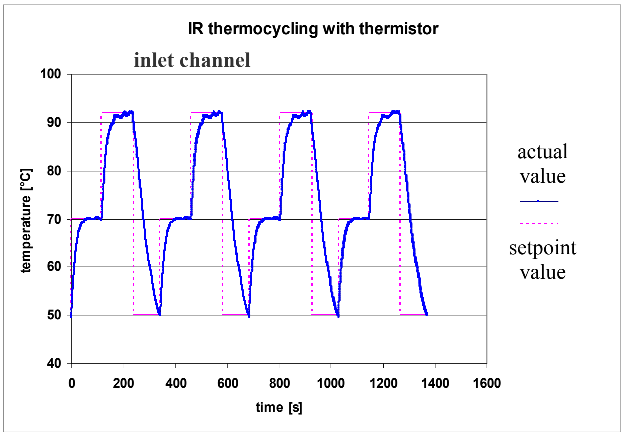

Fig. 8: IR-Thermocycling with sensor in PCR reaction chamber controlled by PID temperature controller

OUTLOOK

After having established a sensitive and dynamic temperature measurement system (Fig. 7) for centrifugal microfluidic disks we now continue to work on the optimization of the closed-loop thermocycling system (Fig. 8). We focus on the further enhancement of our controller performance for both the IR heater and the active cooling by fans. Therefore we implement a PID algorithm with adaptive parameters to our MSP430 microcontroller. Hence we pursue a real-time embedded adaptive controller with adjustable sampling rates which directly takes the wirelessly transferred digital temperature data as input.

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[4] Data sheet of radio transceiver CC2500, Texas Instruments, USA

[5] Data sheet of D/A converter LTC1663, Linear Technology, USA

[6] Data sheet of temp. controller HAPRO 0135, HAPRO Industriegeräte GmbH Solingen, Germany

[7] Data sheet of AC voltage supplier IR21531, International Rectifier, USA

[8] Data sheet of DC voltage regulator LP2980, National Semiconductor, USA

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