DIGITAL PULSE ACTUATED FLOW CONTROL ON A CENTRIFUGAL DISC TOWARDS MULTIPARAMETER WATER QUALITY MONITORING

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ABSTRACT

In this paper we present a novel dissolvable film (DF) based valving architecture for use on the centrifugal microfluidic platform. We seal fluidic reservoirs on a disc substrate with a series of these valves such that, by pulsing the spin rate, the next valve in the series is opened. Thus centrifugal flow control advances from 'analogue' scheme, where valves are successively opened by incremental steps of the rotational frequency, to a 'digital pulse' based method. The performance of these valves is demonstrates through a disc designed towards multi-parameter water quality monitoring.

KEYWORDS: Centrifugal Microfluidics, Lab-on-a-Disc, Dissolvable Films, Digital Control

INTRODUCTION

Over the recent decade the so-called "Lab-on-a-Disc" (LoaD) platform [1] has been of dynamically growing interest in the microfluidics community due to its robustness, low-actuation by a spindle motor cost and its high level of autonomy. Loading of the disc can be implemented by a pipette or syrette, i.e. without pressure-tight connections at atmospheric pressure. This decisive simplification makes the LoaD particularly suitable for deployment as a rugged and portable instrument for applications such as in-field environmental monitoring.

However, as all liquids residing on the rotating disc are subject to the same centrifugal field, a major challenge of the LoaD technology remains the coordination of complex sequential and parallel arrangement of laboratory unit operations (LUOs) such as plasma extraction, metering and mixing. A wide repertoire of such flow control schemes have been developed [2,3] to automate a multitude of common biological and chemical tests composed. Recently, we introduced a robust, DF-based technology whereby valves could be tuned to actuate with sequential increases in the spin rate [4]. Based on fidelity of disc manufacture and the maximum motor speed available, more than six sequential LUOs can be controlled by these valves. In this paper, we present, for the first time, a significant enhancement of this technology where we sequentially concatenate these burst valves with a long, ~40-second dissolution time of the DF.

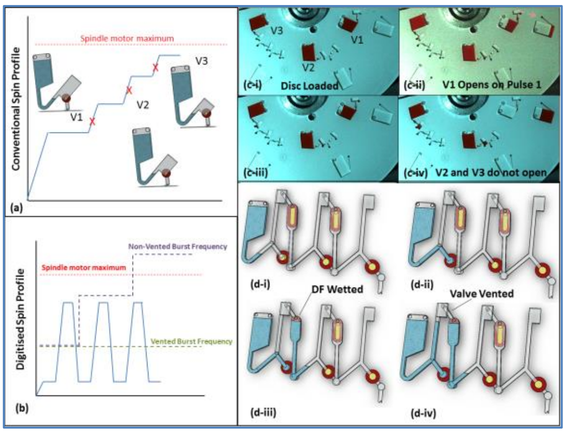

Figure 1: Schematic of valve operation (a) Spin protocol for sequential actuation of conventional DF burst valves. Here, the burst frequency is inversely related to the size of the gas pocket in which the DF is located. Increasing the spin rate opens sequential valves; however the number of valves is limited by the maximum frequency of the spindle motor. (b) Spin profile to actuate the digitised burst valves. (c) Series of 'unvented' sequential valves. It was identified that, when unvented, compresssed trapped gas was pushed into subsequent valves and increased their burst frequency; here Valves 1, 2 and 3 have theoretical burst frequencies of 56 Hz, 71 Hz and 83 Hz, respectively. Only V1 opens as the spindle motor has a maximum spin rate of 60 Hz. (d) Schematic and operation of the vented digital valves. Here, a secondary DF, located after the primary DF at a location open to atmosphere, it wetted after each pulse. On disolution, it vents the pneumatic chamber so that, pnematically, the upstream valve ceases to effect any downstream valves. While a venting channel between the valves is sufficient to allow the valves to actuate in a digitised manner, is was found that this secondary venting mechanism provided superior performance.

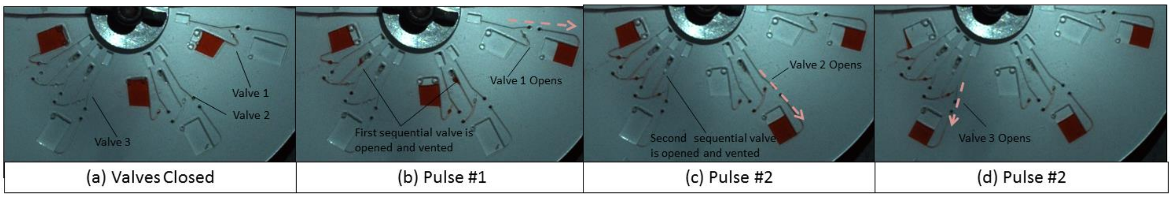

Figure 2: Experimental images of three valves. Valve 1, 2 and 3 are designed to open after the first second and third pulse, respectively.

EXPERIMENTAL AND RESULTS

Each valve is designed to burst above a certain frequency; a transient increase of the spin rate above this critical frequency wets the DF; once the DF dissolves, the rotational frequency is already returned below the critical burst frequency. Thus, placing a series of two such valves to initially seal a fluidic reservoir releases the liquid after two pulses; with three such valves the liquid is released on the third pulse. This valving scheme thus leads to a paradigm shift to centrifugal flow control from 'analog' increases in spin rate to a series of 'digital pulsing'. This "digital revolution" completely lifts the limit on the number of sequential LUOs imposed by the maximum spin rate of the spindle motor (Figs. 1 & 2).

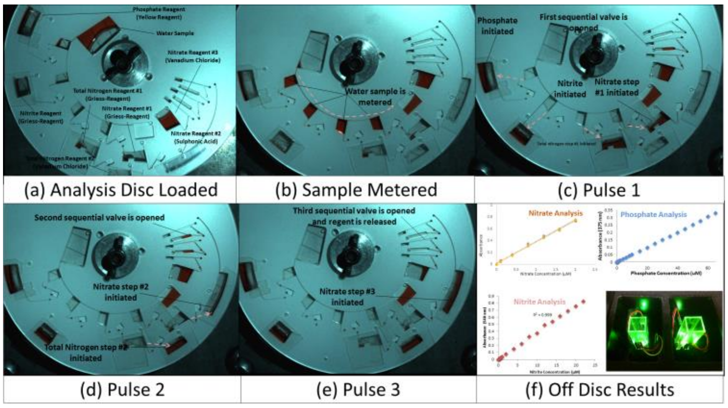

Figure 3: Frame sequence of the water analysis disc with dyed water representative of reagents. (a) Disc architecture. (b) Loaded sample (450 µl) is split into 100 µl volumes. (c) The first disc pulse releases these aliquots into chambers on the periphery initiating the four reactions. (d) The second pulse triggers the second step in the nitrate analysis and the total nitrogen analysis (e) the third pulse triggers the final step in the nitrate analysis. (f) Measurements made from (artificial) sea water spiked with known concentrations of contaminants. These readings were measured off-disc in cuvettes using a custom optical detection system currently under development.

To demonstrate the capabilities of these valves, we present our first steps towards developing a 4-parameter water analysis cartridge. This disc meters a single sample into discrete components. Imposing three spin pulses and an aggressive mixing protocol, the microfluidic architecture performs the time dependent LUOs associated with analyzing phosphate, nitrite, total nitrogen and nitrate with one, one, two and three pulses, respectively (Fig. 3).

CONCLUSION

This new, pulse actuated valving architecture greatly enhances the potential of complex assay integration on the LoaD platform, even without the need for high fidelity manufacturing. This paradigm shift towards "digital" centrifugal platforms will significantly increase reliability of flow control and also drive down cost of disc manufacture and instrumentation.

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