DIFFERENTIAL SECOND-DEGREE OF FREEDOM CENTRIFUGAL MICROFLUIDICS

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ABSTRACT

A Second-Degree of Freedom Centrifugal Platform has been developed which is enabled by a differential gearing system. This system permits the rotation of fluidic chips during centrifugation controlled by two stationary stepper motors. This approach offers key advantages of low-cost, simplicity, and reliability over existing approaches which utilize complex, specialized and expensive electrical slip-rings or wireless power transfer to enable the same concept. The potential of the platform is demonstrated by implementing, using dyed water, the fluidic steps required for DNA purification.

KEYWORDS: Centrifugal Microfluidics, Secondary Motion, Second-Degree of Freedom, Gearing Systems

INTRODUCTION

Second-Degree of Freedom Centrifugal Microfluidics, or Secondary Motion Centrifugal Microfluidics, typically involves mounting a microfluidic chip on the end of a centrifugal arm. The chip is free to rotate about a second axis at the end of the arm; therefore the rotation of the arm generates a centrifugal pumping force while the orientation of the chip is used for microfluidic flow-control. This approach to centrifugal microfluidics is of increasing interest as flow-control is implemented based on the chip architecture and its orientation during centrifugation. This approach is extremely robust compared to other mechanisms. Critically, this flow-control approach does not require chip modification (i.e. addition of active membranes / dissolvable films [1] or localized surface treatments etc.); thus the chips are extremely amenable to mass manufacture.

Secondary motion flow-control has been implemented by a number of research groups using electrical slip-rings [2,3]. In these cases small motors are mounted on the end of the arms. These are controlled directly through the slip-rings or else via a micro-controller which is also mounted on the centrifugal arm. The use of an electrical slip-ring is challenging; namely that low-cost sliprings (using wire brushes) are electrically noisy, while mercury/liquid-metal based slip-rings are specialized and expensive. In view of these limitations wirelessly powered platforms have also been demonstrated and show great potential [4]; however these have the disadvantages of low efficiency power transmission and design complexity.

To circumvent these limitations, we have developed a Second-Degree of Freedom platform which is based on a differential gearing concept. This approach allows full control of the chip orientation using a stationary low-cost stepper motor in a mechanically robust and simple system. We demonstrate the capabilities of the system by implementation, using dyed water, the fluidic steps required for silica-bead based DNA purification.

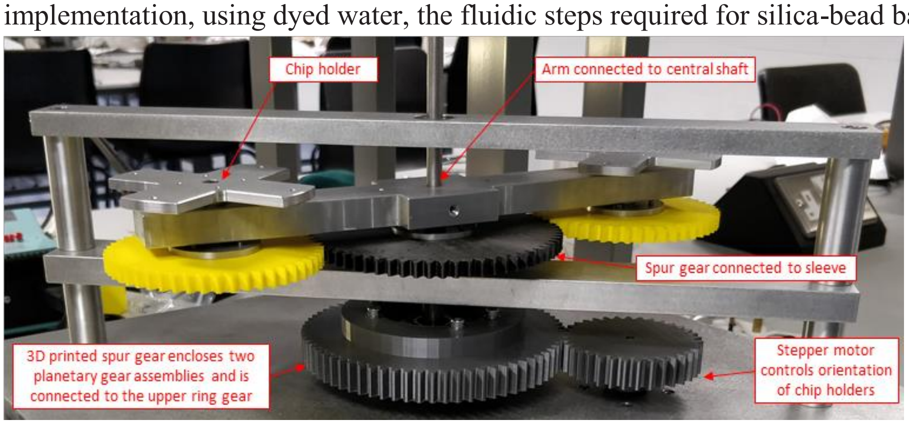

Figure 2: The assembled Differential Centrifugal Spin-stand. The arm is driven directly via a motor connected to the central shaft. The sleeve is driven by the same motor, in the same direction, via the differential gearing system (two planetary gearboxes). Moving the upper ring gear, using the orientation motor, results in the sleeve moving relative to the central shaft. This results in the chip holders changing orientation. The primary motor controls the speed the arm rotates and therefore the centrifugal force. The orientation motor controls the orientation and rate of change of orientation of the chip-holders.

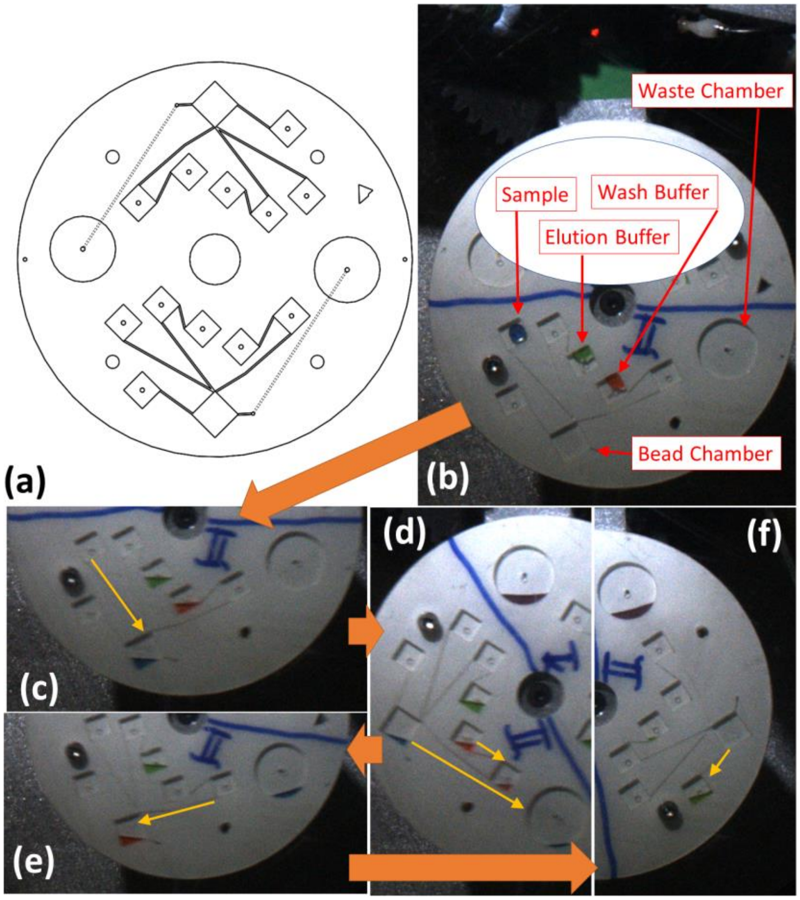

Figure 2: DNA Purification. (a) schematic of chip architecture. The chip is multi-layer to enable non-return flow of liquid. (b-c) The chip at 0º orientation. Sample (blue) flows into the bead chamber (d) The chip at 90 º orientation. The sample (blue) flows into the non-return waste chamber and wash buffer (red) to an intermediate chamber (e) The chip at 0º orientation. The wash buffer (red) is pumped into the bead chamber. Next (not shown), the chip is rotated to 90 º orientation to transfer the wash buffer (red) to the waste chamber. The chip is then orientated to -90º to transfer elution buffer (green) to an intermediate chamber, to 0º to transfer the elution buffer (green) to the bead chamber and then (f) to -90º orientation to pump the elution buffer (green) to a collection chamber. There are two structures per chip and the general architecture is identical to a centrifugal disc in order to use existing assembly jigs. The second structure is blanked out for clarity. Imaging was via a camera/strobe synchronized with the arm using a laser/diode system. Centrifugal arm rotated at 15 Hz.

DESIGN AND OPERATION

The spin-stand functionality is based on mating two planetary (epicycle) gear systems (Matex, USA) to each other via their planetary arms. A low-cost stepper motor is used to drive both a central shaft (directly) and a co-axial sleeve (via the gear assembly) at the same velocity. However, should the ring gear on one (the upper) planetary gear be rotated this will result in the sleeve rotating at a faster or slower velocity than the central axis. The centrifugal arm, supporting the chip-holders, is mounted on the central shaft.

The sleeve is connected to a 3D printed spur-gear which is interlocked with gearing on the chip-holders. Therefore, any displacement of the ring-gear (induced by a second stepper motor) results in a rotation of the chip-holders and so actuation of fluid on the chip. The centrifugal arm can rotate at up to 15 Hz to generate centrifugal force and the secondary motor can induce unlimited 360º rotation of the two chip-holders.

CONCLUSION

We have successfully demonstrated the full articulation of a chip for secondary motion centrifugal microfluidics using a differential gearing system. This low-cost, low-complexity approach does not require an electrical slip-ring or wireless power transfer. It has particular potential for application in low-resource point-of-care / point-of-use diagnostic testing.

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