Automated Microcontrolled Microfluidics with Electrochemical Cancer Diagnostics

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1 Pulse Width Modulation

Pulse width modulation (PWM) is used to control the direction of a servo valve [1]. The width of the electrical pulse controls the angle of mechanical rotation. The pulse event occurs over a defined period of time, usually every 20 ms [1]. The servo will stay in position for as long as the PWM is repeated. For example, if a 1 ms pulse of 6 V is applied to the servo, it will rotate to a position of 0°, conversely if the width is 2 ms a position of 180°, see Figure 1 on the following page. In terms of precision, PWM is a digital signal that does not require analog conversion and is either 'on' or 'off', making it very precise compared to continuously variable analog signals. It is also resistant to noise because interference would need to be strong enough to change a logic 0 (LOW) to a logic 1 (HIGH) [2], or vice versa.

1.1 Library

It is good practice to implement libraries into code to save time and increase efficiency, in this context, efficient means that use of the library does not impose significant learning curves on the user compared with entirely hand written code. To control servomechanisms a 'servo' library was used. The library supported up to 48 servo motors on the Arduino Mega or 12 on the Arduino UNO. This limitation was directly related to the amount of pins on the board, theoretically if more pins were present, this library could utilise them.

2 Syringe Pump

Flow rate within the system was decided by a syringe pump. Syringe pumps are commercially available and provide stable flow rates and greater precision over peristaltic pumps. Most syringe pumps have RS-232 connectivity, so for this reason a RS-232 shield was fitted to an Arduino UNO.

[1] Differs depending on manufacturer

[2] Throughout the manuscript 5 V TTL Logic Levels are used. This is defined by the ATmega328 micro-contoller embedded into the Arduino UNO. TTL is an acronym for Transistor-Transistor Logic. It relies on circuits built from bipolar transistors to achieve switching and maintain logic states. Transistors are essentially electrically controlled switches.

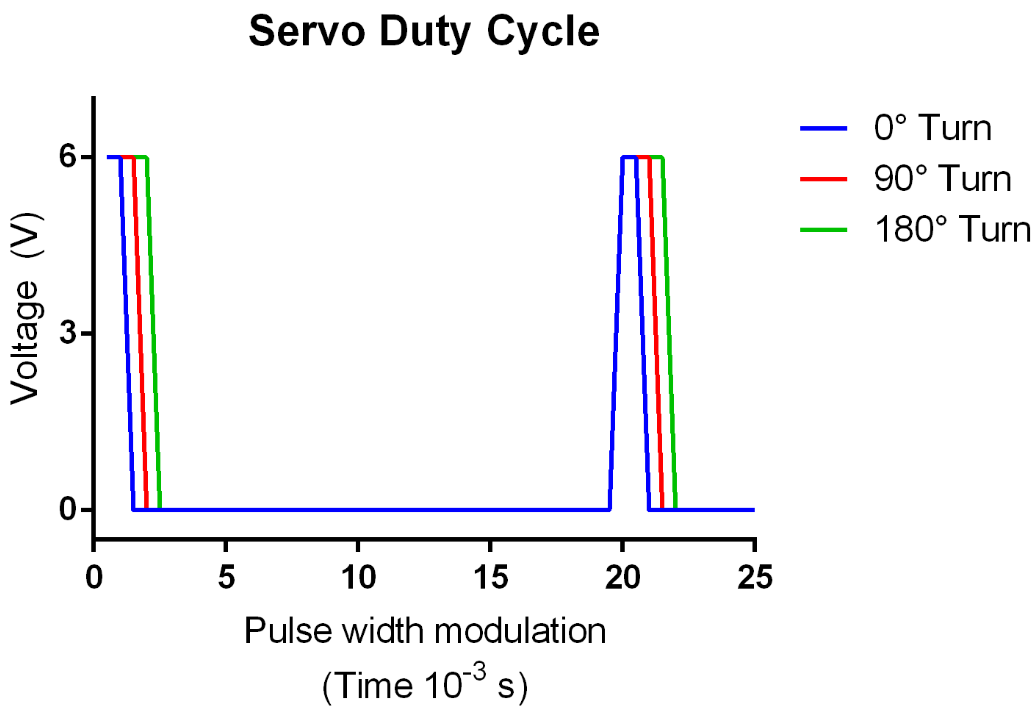

Figure 1: A diagram showing pulse width modulation used to control the direction of a servo valve.

Baud Rate	19200
Frame	10 bit data frame (8N1)
Start Bit	1
Data Bits	8
Stop Bits	1
Parity	None

Table 1: RS-232 Protocol for World Precision Instruments Syringe Pump Model: AL1000.

Syringe pumps introduce slight fluctuations in flow rate and pressure in micro channels caused by a mechanical stepper motor which drives the syringe forward[2, 3]. Despite this, flow-rate control remains superior over pressure controlled methods when pumping in medical and microfluidic settings [4].

Communication with syringe pumps was established using serial protocols. Parity checked the state or condition of a received bit [3], baud rate was the unit determining how fast data was sent over serial line and was measured in bits-per-second. Start and stop bits marked the beginning and end of data packets [4]. The manuscript used an Aladdin syringe pump that operated at specific serial parameters, Table 1.

[3] A form of low-level error checking, it slows down communication but is not necessary and is usually turned off.

[4] While there is always one start bit the number of stops can be either one or two (commonly left at one).

2.0.1 Syringe Pump Serial Connection

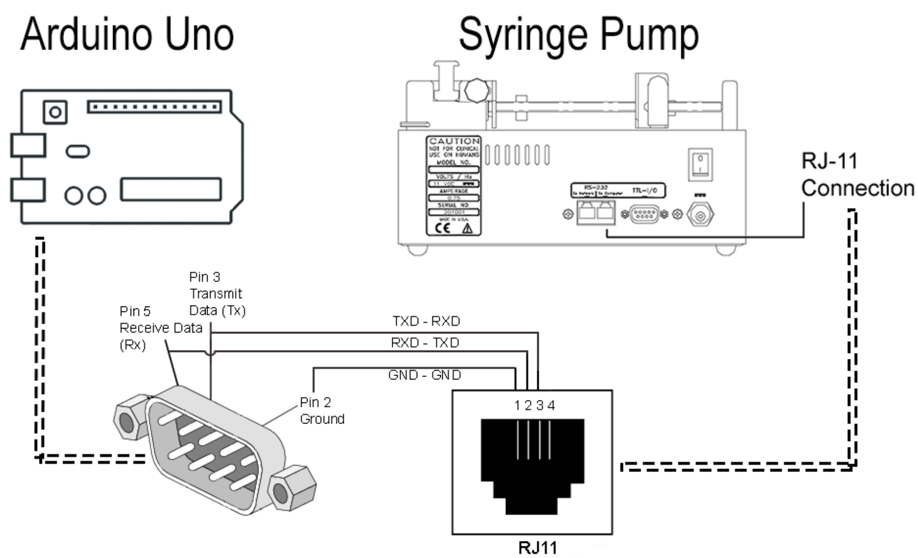

Figure 2: A diagram showing DB9 Pin Out to RJ-11 Pin Out.

The RJ-11 port is present on the rear of the Aladdin AL-1000 syringe pump which is connected to the RS-232 shield present on the Arduino Uno (Fig. 2).

Chr	Hex	Chr	Hex	Chr	Hex
0	30	c	63	o	6F
1	31	d	64	p	70
2	32	e	65	q	71
3	33	f	66	r	72
4	34	g	67	s	73
5	35	h	68	t	74
6	36	i	69	u	75
7	37	j	6A	v	76
8	38	k	6B	w	77
9	39	l	6C	x	78
a	61	m	6D	y	79
b	62	n	6E	z	7A

Table 2: ASCII Table

2.0.2 ASCII Table

ASCII stands for American Standard Code for Information Interchange. In order to control the syringe pump, the conversion Table 2 was used to obtain hexadecimal values converted from plain text. The simplified ASCII Table shows only the numbers 0 to 9, and lowercase character letters a to z.

3 Flow Distribution Path

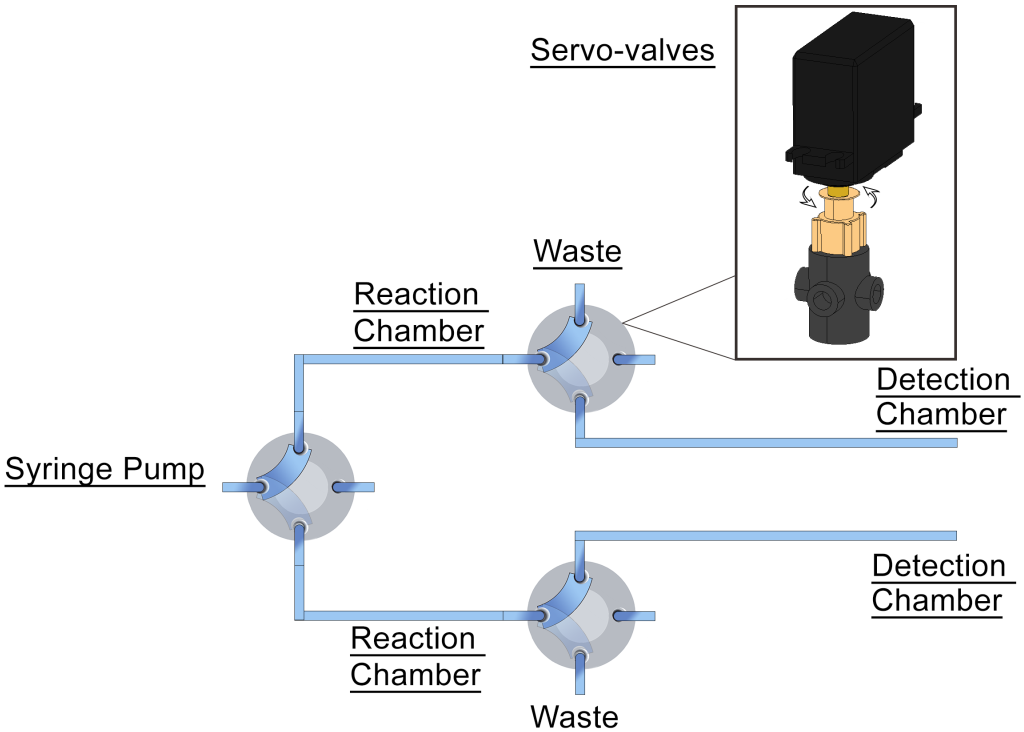

Figure 3: A diagram showing microfluidic flow through the system. Shown inset is a servo-valve which directs flow to either waste or detection streams.

4 Electrochemical detection cell protein format

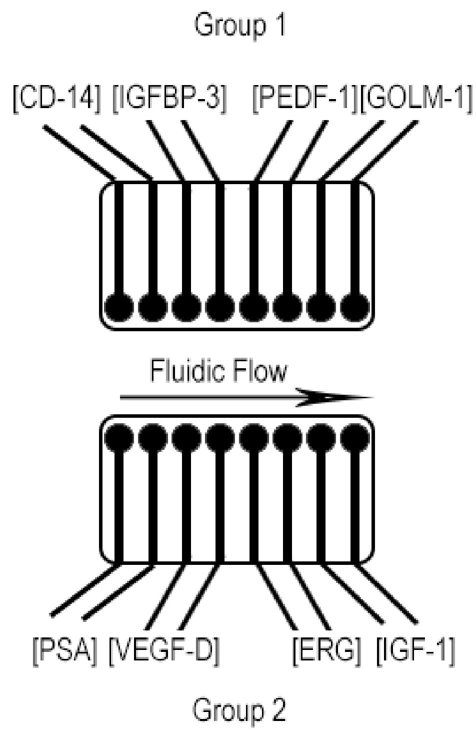

Figure 4: A diagram showing microfluidic flow through the electrochemical detection chamber. Shown is proteins to be assayed and their respective groups.

Step	Description	Flow Rate	Time
1	Flush detection chamber connected to chamber 1	$2000\,\mu l\,min^{-1}$	3min
2	Flush chamber 1 to waste	$2000\,\mu l\,min^{-1}$	3min
3	Flush detection chamber connected to chamber 2	$2000\,\mu l\,min^{-1}$	3min
4	Flush chamber 2 to waste	$2000\,\mu l\,min^{-1}$	3min

Table 3: Flushing Protocol

5 Power Consumption of Flushing Protocol

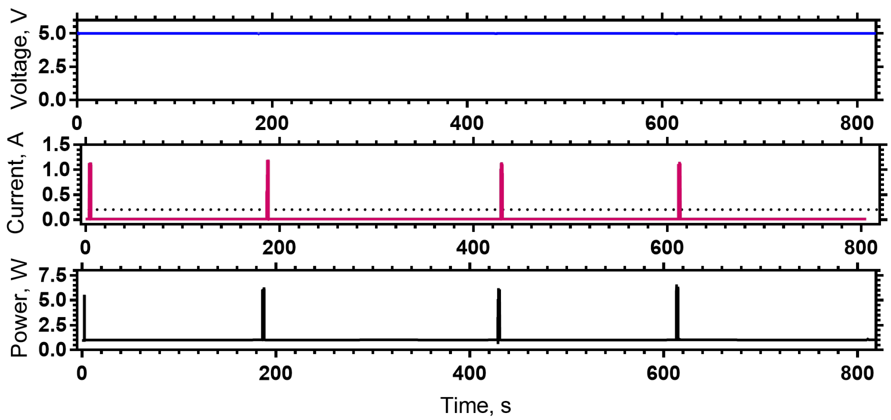

Figure 5: Power consumption for running the flushing protocol (Table 3). A digital multimeter (Keithley 2700) was connected to the system to measure the voltage V and current A of the power source at a frequency of 10 Hz. Power consumption is calculated as P = VI. The flushing protocol takes about 13 minutes to complete. Horizontal dashed lines (black) indicate the average values of the measured parameters. Refer to Table 3 for detailed descriptions of each step.

$$P = VI \tag{1}$$

6 Electronics Materials List

Item	Description
1	Arduino Uno
2	L293D Driver
3	Computer Disk Drive
4	Breadboard
5	Breadboard Wires
6	USB Cable
7	Breadboard power supply
8	LCDs (2)
9	Servos (3)
10	3M Electrode Clip
11	Passive Buzzer
12	RS-232 Shield V2
13	RJ-11 Cable
14	LEDS (2)
15	Resistors (220ohm)
16	USB A male to male cable
17	Power adapter (AC 110-240V input, DC 5V 1A output)

Table 4: List of materials used.

References

[1] Paul Krause, Oleg Wasynczuk, and Steven Pekarek. *Electromechanical Motion Devices*. John Wiley & Sons, Inc., Hoboken, NJ, USA, 2nd edition, mar 2012.

[2] Zida Li, Sze Yi Mak, Alban Sauret, and Ho Cheung Shum. Syringe-pump-induced fluctuation in all-aqueous microfluidic system implications for flow rate accuracy. *Lab Chip*, 14(4):744, 2014.

[3] Wen Zeng, Ian Jacobi, David J Beck, Songjing Li, and Howard a Stone. Characterization of syringe-pump-driven induced pressure fluctuations in elastic microchannels. *Lab Chip*, 15(4):1110–1115, 2015.

[4] Thomas Ward, Magalie Faivre, Manouk Abkarian, and Howard A. Stone. Microfluidic flow focusing: Drop size and scaling in pressureversus flow-rate-driven pumping. *Electrophoresis*, 26(19):3716–3724, oct 2005.