

## **Programmable Magnetic Robot (ProMagBot) for Automated Nucleic Acid Extraction at the Point of Need**

Anthony J. Politza<sup>1</sup>, Tianyi Liu<sup>2</sup>, and Weihua Guan<sup>1, 2, 3\*</sup>

<sup>1</sup> Department of Biomedical Engineering, Pennsylvania State University, University Park 16802,  
USA

<sup>2</sup> Department of Electrical Engineering, Pennsylvania State University, University Park 16802,  
USA

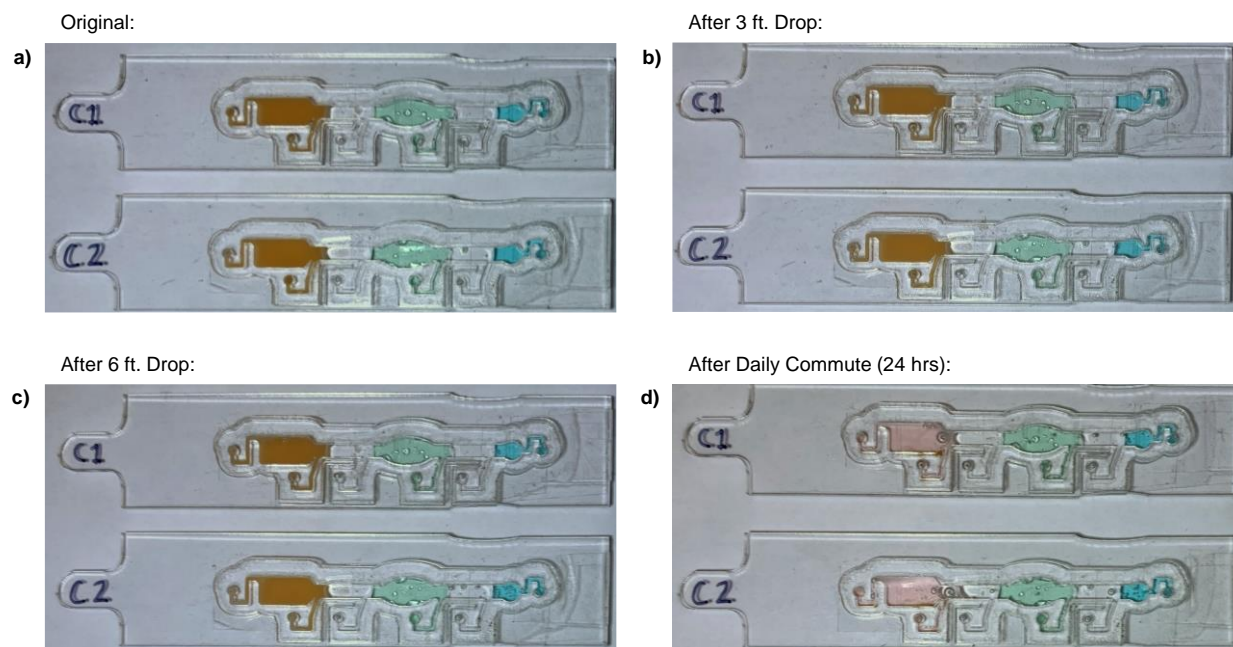
<sup>3</sup> School of Electrical Engineering and Computer Science, Pennsylvania State University,  
University Park 16802, USA

\* Corresponding Author, Email: wzg111@psu.edu

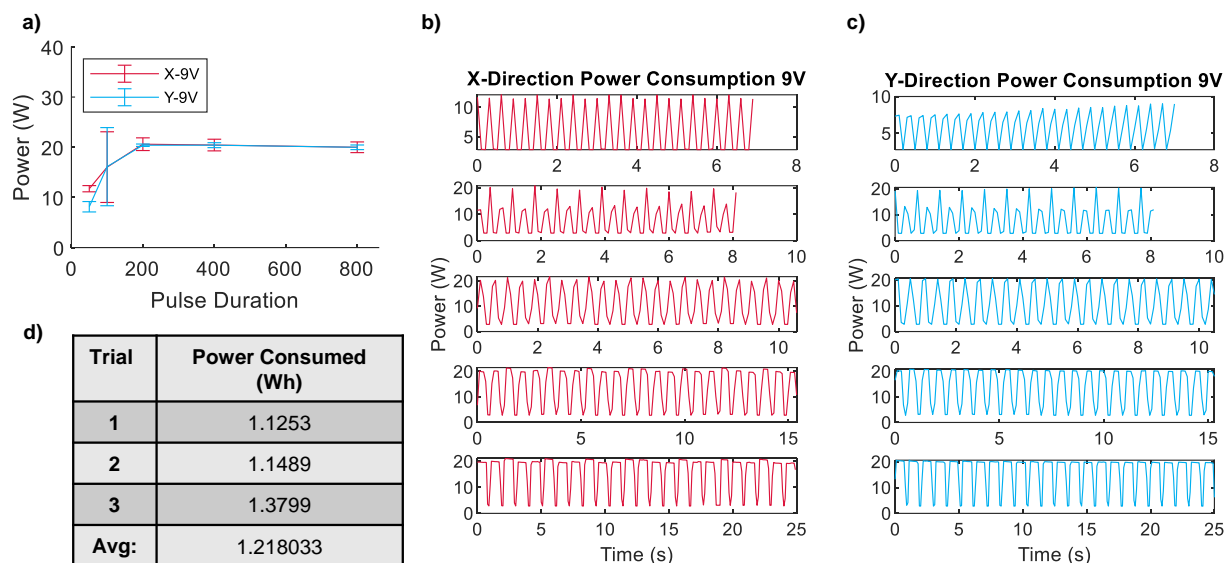
### **Contents**

Supplementary Figures .....	2
Supplementary Tables.....	4
Supplementary Videos .....	8
Supplementary References.....	9

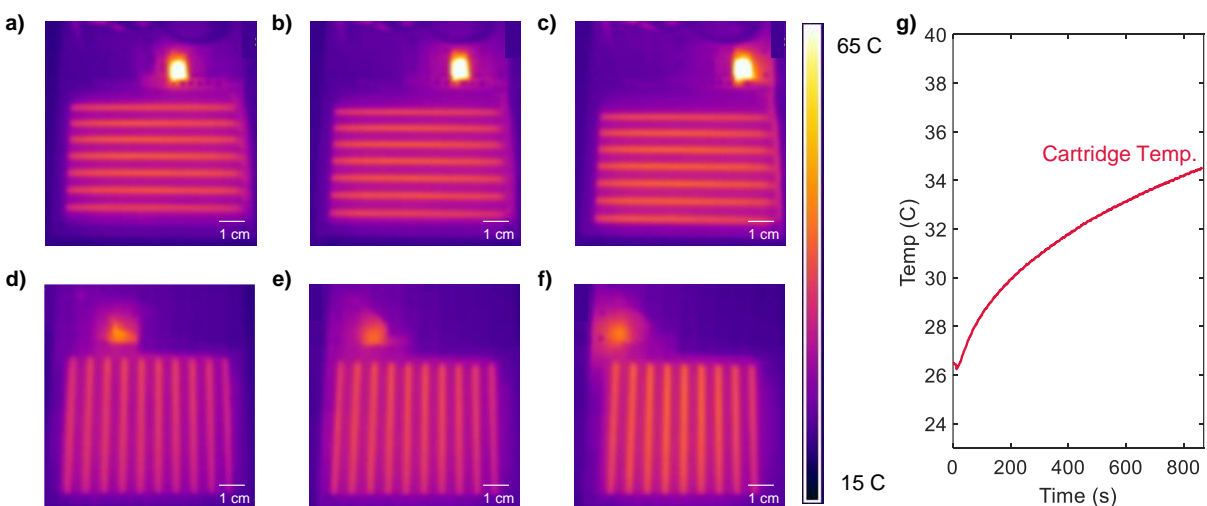
## Supplementary Figures



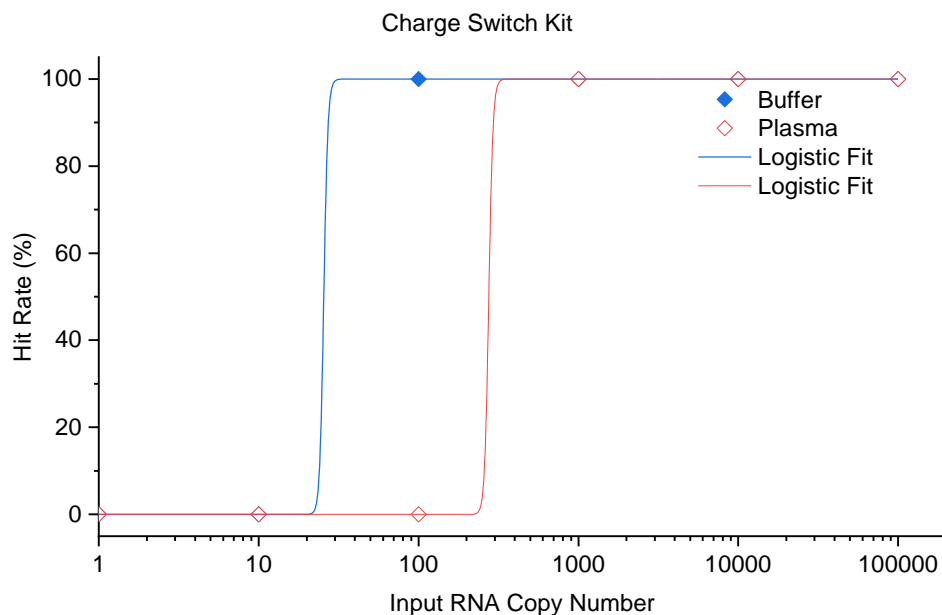
**Figure S1.** Cartridge Durability Testing. (a) Original cartridges directly after fabrication and loading. (b) Cartridges were dropped from 3ft and then imaged. (c) Cartridges were then dropped from 6ft and then imaged. (d) Cartridges were sealed in plastic zipper bags, carried on-person during a daily commute, and then imaged.



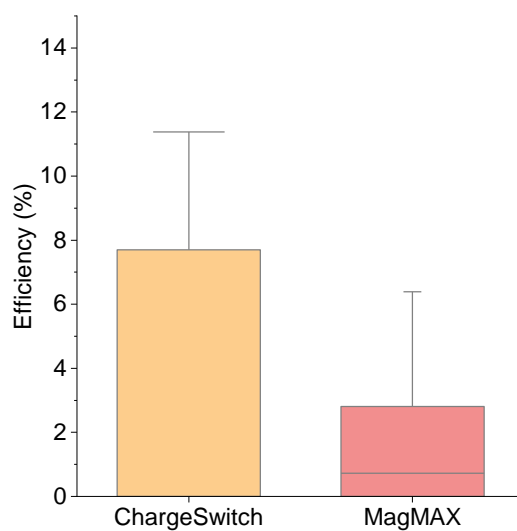
**Figure S2.** Device power consumption. (a) Power per pulse for varying pulse durations. The activation frequency was kept at 1 Hz, and 25 pulses were recorded. Raw data plots of power for each recorded trial starting from 50 ms (top) to 800 ms (bottom) for X-Direction movement (b) and Y-Direction movement (c). (d) Summarized total power consumption of the device when recorded over three separate trials.



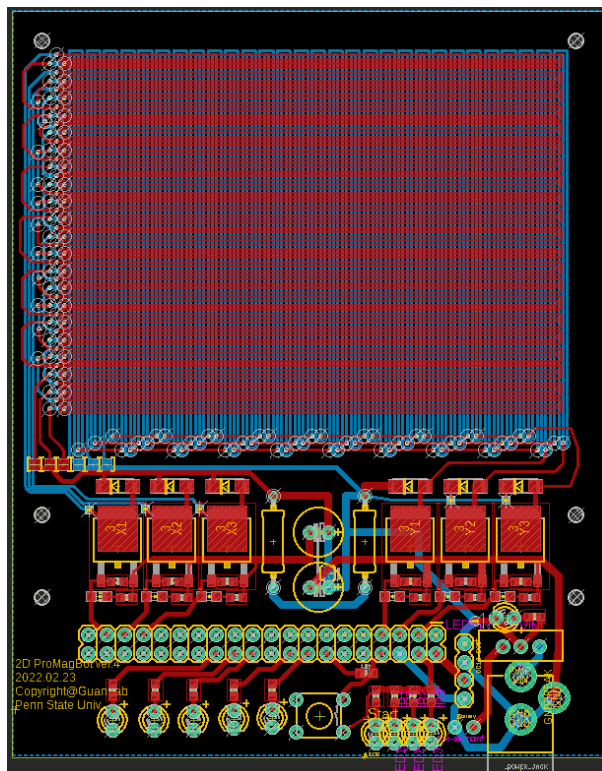
**Figure S3.** Thermal distribution and response. Thermal images of each coil group for Y-Direction motion (a)-(c) and X-Direction motion (d)-(f). Note that the MOSFETs are the hotspot in each image. However, after 5 s, the coils and PCB do not reach excessive temperatures above 60 C. (g) Cartridge temperature throughout an extraction procedure. Temperatures do not rise above 35 C.



**Figure S4.** Hit rate analysis for the Charge Switch extraction kit when operated with the ProMagBot. Limits of efficiency were determined from the smallest copy number to show 100% ( $n > 3$ ).



**Figure S5.** The extraction efficiency of two commercial bead kits using the ProMagBot protocol. Efficiency was calculated from an extracted sample analyzed with a qRT-PCR assay ( $n = 6$ ).



**Figure S6.** Hardware design of the ProMagBot PCB. Six transistor switches control 3-phases of coils along both the X and Y directions.

## Supplementary Tables

Table S1. Cartridge and assay materials

Reagents	Vendor	Function	Stock Vol (mL)	Unit Cost (\$)	Volume (μL)/rxn	Ext Cost/rxn
Lysis Buffer	Invitrogen	Sample Prep.	25	6	100	0.02
Wash Buffer	Invitrogen	Sample Prep.	37.5	54	85	0.12
Elution Buffer	Invitrogen	Sample Prep.	11	35	30	0.10
Proteinase K	Invitrogen	Sample Prep.	0.25	10	1	0.04
Magnetic Beads	Invitrogen	Sample Prep.	5	220	20	0.88
Mineral Oil	Sigma Aldrich	Sample Prep.	1000	42	160	0.01
Solvent	ePlastics	Cartridge Solvent	118	9.9	100	0.01
Material	Vendor	Function	Stock Vol (sq. m.)	Unit Cost (\$)	Volume (sq. mm)/rxn	Ext Cost/rxn
1/32" Acrylic Sheet	ePlastics	Cartridge	0.5	16.13	20	0.65
1/16" Acrylic Sheet	ePlastics	Cartridge	0.5	9	40	0.72
<b>Total</b>						<b>\$3.91</b>

Table S2. ProMagBot device components

System	Vendor	Description	Function	Unit Cost (\$)	Unit Qty.	Ext Cost (\$)
Electronics	Digikey	DC Barrel Power Jack/Connector	Power Connector	\$0.69	1.00	\$0.69
Electronics	Digikey	Power Resistor, 10Ω	Power stabilizing	\$0.01	2.00	\$0.01
Electronics	Digikey	Capacitor 10uF	Power stabilizing	\$0.15	2.00	\$0.29
Electronics	Digikey	N Channel Power MOSFET	Switch for PCB coils	\$0.88	6.00	\$5.25
Electronics	Digikey	SMD Blue LED	Coil Group indication (internal)	\$0.53	6.00	\$3.18
Electronics	Digikey	Resistors 510 Ohm	Resistor for LEDs	\$0.01	9.00	\$0.09
Electronics	Digikey	Cree Wide Angle LED	Illumination of Stage & Robot for camera vision	\$0.07	3.00	\$0.20
Electronics	Adafruit	Jumper Wires	Electrical Connections	\$0.25	20.00	\$5.00
Electronics	Digikey	Switch	Wall or Battery Selection	\$1.09	1.00	\$1.09
Electronics	Digikey	Indication LED bar	User Indicator	\$2.09	1.00	\$2.09
Electronics	Digikey	Tactile Button (Momentary)	Start Device extraction protocol	\$5.99	0.01	\$0.05
Electronics	Digikey	Indication LED	Power Light	\$0.98	1.00	\$0.98
Electronics	Adafruit	UBEC DC/DC Step-Down Converter	Rasp-Pi Power Delivery	\$9.95	1.00	\$9.95
Electronics	Canakit	Raspberry Pi 4	Controller and OS	\$75.00	1.00	\$75.00
Electronics	Canakit	Pi Camera	Camera	\$25.00	1.00	\$25.00
Power Supply	HobbyKing	Zippy Compact Battery	Battery	\$13.00	1.00	\$13.00
Power Supply	HobbyKing	Charging Cable	ProMagBot Charging	\$6.00	0.10	\$0.60
Power Supply	HobbyKing	XT60 Splitter Cable	Power Delivery & Charging	\$3.99	1.00	\$3.99
Power Supply	Amazon	9V Power Supply	External Power Supply	\$9.98	1.00	\$9.98
Magnet	K&J Magnets	Neodymium Disc Magnet Nickel	Magnetic Robot	\$0.43	1.00	\$0.43
PCB	OSH Park	Custom PCB - Manufacturing	EM and System Control	\$22.00	1.00	\$22.00
Case	Inventables	1/8" PMMA	Viewing Window and Illumination Guide	\$15.00	0.03	\$0.45
Case	MakerBot	3D Printed ABS Filament	Electronic Housing	\$60.00	0.50	\$30.00
Case	MakerBot	3D Printed ABS	Magnet Spacer	\$60.00	0.01	\$0.60
Case	McMaster-Carr	Nylon M2 Screws & Nuts	Assembly	\$11.22	0.20	\$2.24
<b>Total Cost</b>						<b>\$209.32</b>

**Table S3. RT-qPCR primer set targeting HIV-1 <sup>1</sup>**

<b>Component</b>	<b>Sequence (5' – 3')</b>
Forward	CATGTTTTTCAGCATTATCAGAAGGA
Reverse	TGCTTGATGTCCCCCACT
Probe	FAM-CCACCCCAAGATTTAAACACCATGCTAA-Q

**Table S4. Extraction workflow comparison**

<b>Workflow</b>	<b>Number of Manual Steps</b>	<b>Number of Pre-Loading Steps</b>	<b>Cost per Extraction</b>	<b>Manual Processing Time (min)</b>	<b>Total Time (min)</b>
ChargeSwitch	9		N/A \$ 6.78	20	20
MagMAX	8		N/A \$ 7.14	20	20
ProMagBot	4	4	\$ 3.91	3-5	20

## Supplementary Videos

**Supplementary Video S1. (Duration 1 m 25 s)** Demonstration of Magnet-On-Top method for passive precipitation mixing. As the magnet approaches the beads in the solution below, they are collected at the top surface. When the magnet is removed, the beads precipitate through the solution, inducing mixing.

**Supplementary Video S2. (Duration 2 m)** Workflow of automated ProMagBot extraction system.

**Supplementary Video S3. (Duration 21 s)** Representation of multiple pathways of motion in 2D space.

**Supplementary Video S4. (Duration 2 m 19 s)** Programmed pathway and bead response during nucleic acid extraction procedures.



## Supplementary References

1. S. Palmer, A. P. Wiegand, F. Maldarelli, H. Bazmi, J. M. Mican, M. Polis, R. L. Dewar, A. Planta, S. Liu and J. A. Metcalf, *Journal of clinical microbiology*, 2003, **41**, 4531-4536.