Open hardware for random access plate storage

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Abstract

We describe a design that uses 3D printed parts and off-the-shelf components to create an inexpensive system for automated storage and retrieval of microplates. In this way, a robotic system for storage of 24 plates can be built for less than $400.

Introduction

Automation has the power to transform the scale of discovery possible in biology. At present, however, a key limiting factor is the high cost of the specialised equipment needed. Commercially available automated versions of common biological equipment can cost orders of magnitude more than their manual counterparts. Nevertheless the components of many such systems are not inherently expensive. The advent of widespread 3D printing technology, and the availability of aluminium extrusions that simplify linear motion, provides opportunities for purpose-built labware created in-house using open source designs (Baden et al., 2015; Coakley and Hurt, 2016).

Automation increases throughput, in part because robots can work continually. But to truly realise these benefits, and minimise the need for human intervention, automated systems needs the ability to store the physical inputs and outputs to their processes, typically in the SBS standard microplate format (ANSI/SLAS, 1-2004).

Here we present a simple low-cost design which allows the vertical racking of 6 to 24 standard sized microplates with automated storage and retrieval. This provides a storage system that can be interfaced with other robotic systems.

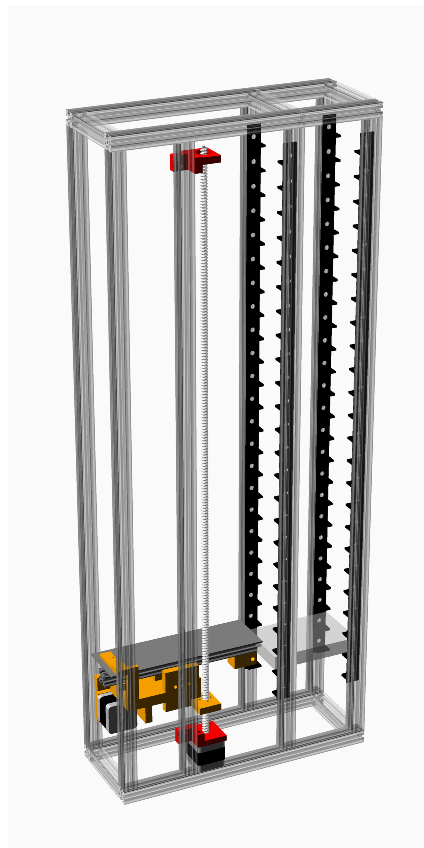

Figure 1: A 3D rendering of the components of the plate storage system in one example design. OpenBuilds V-slot aluminium extrusion is shown in transparent gray; the stainless steel sheet is also shown in gray. The two NEMA-17 motors are shown. 3D printed components are as follows: in red the motor holder and the bearing holder, in orange the Z carriage in two parts, and in black the plate holder modules.

Design

Frame structure

The framing of the device, and the rails for linear motion, are made from 20 mm V-slot aluminium extrusion

(OpenBuilds). The slots in this extrusion easily permit the mounting of the device to other equipment, or to the wall or floor for stability. One advantage of open hardware for this design is that all dimensions can be varied according to the user's needs. By choosing a small height, a compact system capable of storing a small number of plates can be created, whereas a 900 cm height allows storage of at least 24 microplates. Although Fig 1 depicts the simplest design, other possibilities are possible such as an L shaped structure (Fig 3) which provides a large space at the top where the plate can be presented to bulkier handling devices.

Plate shelves

Slots for microplates are created by attaching a 3D printed edge shelving strip ('plateholder.stl') to four of the uprights of the framing structure. Shelves are by default at 33 mm spacing though adaptation to deep well plates could easily be achieved. Shelving strip should be painted with latex paint ('PlastiDip') for increased grip.

Vertical motion

Movement of the 3D printed plate carrier ('Zcarriage.stl') up and down by is made possible by bolting the Z-carriage to an OpenBuilds mini-V gantry which runs up and down one of the extrusions. It is controlled by a T8 leadscrew, attached to the shaft of a NEMA 17 stepper motor mounted at the bottom of the device ('motorholder.stl'). The top of the leadscrew is secured by a 608ZZ bearing at the top of the rail ('bearingholder.stl'). The use of a leadscrew ensures that the Z carriage will remain in place in the event of power failure.

Horizontal motion

Motion of the plate carrier horizontally, into the plates and away from them, is achieved with a NEMA-17 motor that moves a GT2 timing belt, running over two 606ZZ bearings. The belt is attached (beltclampA, beltclampB.stl) to a sheet of stainless steel (again painted with latex for grip). The steel sheet is attached to a second mini-V gantry which moves back and forth over a V slot extrusion mounted on top of the Z-carriage. The length of horizontal movement is determines by the position at which the second piece of the Z carriage (ZcarriageB.stl) is mounted along the extrusion.

Limit switches can be attached for both the X and Z axes to allow automatic homing.

Electronics

An affordable and readily-available solution for controlling the two axes that make up the stacker is to use a 3D printer controller, such as the RAMPS board with an Arduino Mega. These boards connect directly to the stepper motors and also have connectors for endstop switches if these are desired. Control from a computer is then achieved by sending G-code commands through the USB port. Acceleration and maximum speed can be altered to suit the sensitivity of the samples being stored.

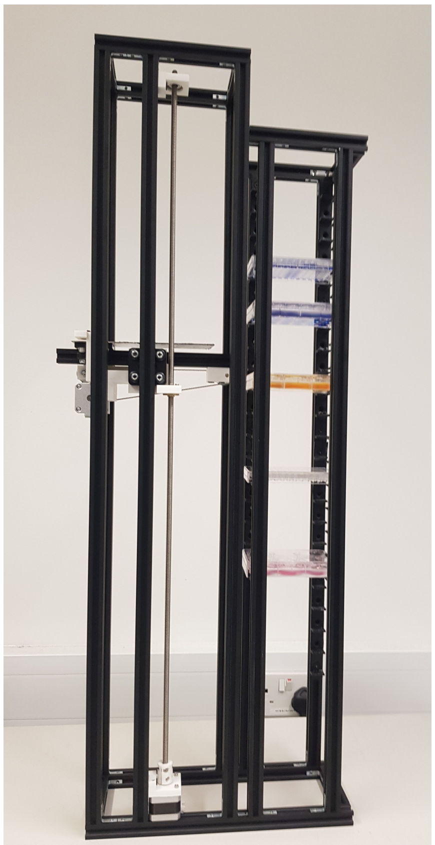

Figure 2: Photograph of a customised version of the apparatus. Note that in this design there is an open area above the stack of plates where the plate can be presented to other robotic devices which require space for access.

Figure 3: This figure is a real-time video of the device in Fig. 2, demonstrating plates being shuffled. It provides a sense of the speed of operation, and mechanism of action.

Costings

Number	Model	Unit cost	Total cost
32	Hidden right angle brackets	1.8	57.6
40	6mm M5 bolts	0.03	1
1	Assorted lengths of M5 bolt	2	2
1	M3 nuts and assorted M3 bolts	2	2
2	mini-V gantry kits	30.75	61.5
1	sheet stainless steel	5	5
1	GT2 timing belt	2.5	2.5
1	GT2 pulley	5.5	5.5
2	NEMA-17 motors	17.5	35
1	1m T8 leadscrew & nut	40	40
1	608ZZ bearing	1.5	1.5
2	606ZZ bearing	1.2	2.4
2	M6 bolts & large washers	1	2
7	V-slot uprights (900mm)	10	70
4	V-slot X pieces (370mm)	5	20
5	V-slot Y pieces (100mm)	1.5	7.5
1	V-slot linear rail for Z carriage	5	5
1	RAMPS board & Arduino & A4988 motor drivers	25	25
1	12V power supply	25	25
1	Assorted 3D-printed pieces	20	20
		Total	390.5

Table 1: Approximate costings to construct a device capable of storing 24 microplates. Price for 3D printing is an estimated cost for material, and assumes access to a 3D printer.

Discussion

The design we introduce here provides a foundation for microplate storage in an open-source robotic system and demonstrates that this can be achieved at minimal cost.

Although ambient plate storage is suitable for some applications, in other cases incubation may be be needed at a particularly temperature, or at a particular humidity or gas composition. It is possible to imagine extending this design by encasing the frame in an insulated/airtight case to achieve these aims. Instructions for building a CO2 incubator are already available from the Pelling laboratory and might synergise well with this design.

Similarly, a barcode scanner could be added to verify plate identity and minimise the possibility for human error. The advantage of an open-source design is that such improvements can now readily be implemented in future iterations.

Supplemental files and instructions

Parametric 3D design

PlateStorer.scad - this is an OpenSCAD file. It is a script which generates a complete 3D model of the device, including all 3D printed components. It can be used to explore the device in three dimensions, and to edit the design to incorporate new features.

Stereolithography files

Download all STL files

ZcarriageA.stl and **ZcarriageB.stl**. You must print both of these files once. Mount a piece of OpenBuilds extrusion to part A with M5 bolts and drop-in tee nuts and then mount part B below this extrusion to set the range of movement for the carriage. Use M6 bolts through the 6mm holes to mount 606ZZ bearings (flanked by large washers) to act as pulleys for the GT2 belt. Attach a GT2 pulley on the shaft of a NEMA-17 motor and mount the motor to the Z-carriage using M3 bolts. Place the T8 nut in the holder and mount with more M3 bolts. Mount the whole Z carriage assembly to a mini-V gantry with M5 bolts.

BeltattachmentA.stl and **BeltattachmentB.stl**. Print both of these and clamp them together with an M3 bolt and nut to join the two ends of the GT2 belt together. Next drill a hole in the stainless steel sheet and attach to BeltattachmentA with another M3 bolt and nut. The stainless sheet should also be drilled with two further holes in order to attach to a mini-V gantry plate.

MotorHolder.stl and BearingHolder.stl. Print one of each. Mount the motor with M3 bolts. and mount both to the extrusion with M5 bolts and drop-in tee nuts. Set the 608ZZ bearing in the bearing holder.

ShaftCoupler.stl. This can be used to clamp the motor shaft to the T8 drive screw. Alternatively a commercial coupler can also be used.

PlateHolder.stl. You will need 4 copies of this print for every 6 plates you want to store. Mount to linear rail with M5 bolts and drop-in tee-nuts.

References

ANSI/SLAS. Microplates — Footprint Dimensions, 1-2004.

Tom Baden, Andre Maia Chagas, Gregory J. Gage, Timothy C. Marzullo, Lucia L. Prieto-Godino, and Thomas Euler. Correction: Open Labware: 3-D Printing Your Own Lab Equipment. *PLOS Biology*, 13(5):e1002175, may 2015. doi: 10.1371/journal.pbio.1002175. URL https://doi.org/10.1371%2Fjournal.pbio.1002175.

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