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Approaches to open source 3-D printable probe positioners and micromanipulators for probe stations

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ABSTRACT

Three types of highly-customizable open source probe positioning systems are evaluated: (a) mostly 3-D printed, (b) partially printed using OpenBeam kinematic constraints, and (c) a 3-level stack of low-cost commercial single axis micropositioners and some printed parts. All systems use digital distributed manufacturing to enable bespoke features, which can be fabricated with RepRap-class 3-D printer and easily accessible components. They are all flexible in material choice for custom components. The micropositioners can be set up for left-right use and flat or recessed configurations using either mechanical or magnetic mounting. All systems use a manual probe holder that can be customized and enable a quick swap probe system. System (a) is purchased for $100 or fabricated for <$5, (b) fabricated for $25, and (c) fabricated for $145. Each full turn of a knob moves an axis 0.8 mm for (a) and 0.5 mm for (b, c) providing externally measured positional control of 10 μm for the latter. All three designs can utilize a customizable probe holder and tungsten carbide needle for $56. The designs are validated using microchips with known feature sizes and underwent mechanical stress tests. The maximal deflection of (a) was >200 μm, (b) 40 μm and (c) 10 μm. A tradeoff is observed for 3-D printed percent between cost and accuracy. All systems provided substantial cost savings over proprietary products with similar functionality.

Specifications table

Hardware name	*Open Source 3-D Printable Probe Positioners*
Subject area	• Engineering and Material Science
Hardware type	• Measuring physical properties and in-lab sensors • Electrical engineering and computer science
Open Source License	(a) Cc-by-SA, (b) and (c) GNU General Public License (GPL) v3.0
Cost of Hardware	(a) $5–99, (b) $25, (c) $145 for manipulator, with $56 probes
Source File Repository	https://osf.io/r264u/

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1. Hardware in context

One of the primary benefits of the use of an open hardware approach to design is the ability to quickly and easily build upon the work of others [1,2]. An example of the success of this approach is the evolutionary development of the self-replicating rapid prototyper (RepRap) 3-D printer [3–5]. RepRaps and their various commercial variants have obtained 3-D printing qualities of interest to the scientific community and is now widely used to fabricate scientific hardware [6,7] including biological [8,9], biotechnological [10], chemical [11–15], nanotechnological [16], medical [17], materials [18], microfluidics [19–23] and even remote sensing [24]. In addition, to the use of open source hardware designs being shared for digital distributed manufacturing, there are also open hardware designs that are primarily distributed conventionally. For example, OpenBeam [25], is an extruded aluminum framing system meant for rapid prototyping and built using standard hardware (T-slots for DIN934 M3 nuts) instead of proprietary and expensive fasteners. OpenBeam has been adopted to improve several types of 3-D printers [26,27] as well as for robotics [28] and opto-mechanical equipment [21,29].

To contribute to this trend, this paper evaluates three types of highly-customizable open source probe positioning systems for micromanipulators in probe stations: a) a mostly 3-D printed positioner making using of only a few mass produced fasteners, b) partially 3-D printed system using OpenBeam kinematic constraints, and c) a 3-level stack of low-cost commercial single axis micropositioners and some key 3-D printed parts. A microscopic probe positioner is used to make electrical contacts to test microelectronics under a microscope and demands a level of precision of movement that cannot be achieved by the unaided human hand [30]. Manually adjustable probe positioners are utilized in thousands of microelectronics labs while prototyping or manufacturing in small volumes. In addition to fully automated production wafer probers, manual systems are still used in parallel for process monitoring and debugging purposes. In most cases, contact pads as small as $50 \times 50\ \mu m$ need to be reliably contacted. Sometimes it is beneficial if smaller structures all the way to a $10\ \mu m$ level are accessible. These 3-D printable probe positioners combine the benefits from custom digital replication using a RepRap 3-D printer and the wide availability of non-printed parts including fasters for (a) and (b), extruded linear railing system of OpenBeam for (b), and mass produced single axis micropositioners for (c).

Micromanipulators are either precision machined [30] or purchased commercially for significant costs generally over $1000 USD per probe positioner. This paper evaluates previous attempts to design 3-D printed manipulators for biological experiments, (a) which have been made mechanical [31] as well as automated [8] and presents two new open source micromanipulators (b) and (c). Here highly-customizable open source 3-D printable probe positioners are developed based on a digital distributed manufacturing design procedure [32]. Other previous automated probes, which were used as four-point probes [33,34], were not appropriate for either microelectronics single probe applications or for multiple probes testing various sample geometries of different types of electronic devices. All three systems evaluated use digital distributed manufacturing to enable five bespoke features: 1) fabrication with RepRap-class 3-D printer and easily accessible components; 2) flexibility in material choice for custom components; 3) left-right, flat and recessed configurations; 4) mechanical and magnetic mounting; and 5) a manual probe holder customization and quick swap probe system. The design are validated and tested and the cost saving of the probe positioning systems are compared against commercially available products with similar functionality.

2. Hardware description

2.1. Nearly fully 3-D printed mechanical manipulator

Backyard Brains (BYB) of Ann Arbor Michigan, a company attempting to democratize neuroscience research by making neuroscience equipment low cost, developed an open source 3-D printable mechanical manipulator [31]. It was later redesigned in OpenSCAD [35] and upgraded with optional servo mounts [8,36]. The commercial version was tested here, which cost $99. It is an elegant design, which is made almost completely out of a minimum number of simple 3-D printed parts and a minimum number and variety of fasteners as seen in Fig. 1. The custom parts can be fabricated with any form of fused filament fabrication (FFF) – based 3-D printer such as a RepRap or any other 3-D printer with better than $100\ \mu m$ positional accuracy. The components are small enough to fit individually on even the smallest FFF 3-D printer beds. The parts can also be fabricated from other 3-D printing processes such as stereo lithography or laser sintering. This makes the accessibility of manufacturing high as such devices are widely available now in fab labs, makerspaces, universities and now many libraries as well as 3-D printing services (both brick and mortar and online). As the primary components can be 3-D printed from any FFF-available thermopolymer they can be customized for specific testing environments. Here orange acrylonitrile butadiene styrene (ABS) is demonstrated for probing at room temperature. However, more exotic 3-D printing polymers can be used for more challenging testing environments. For example, uv-stable acrylonitrile styrene acrylate (ASA) can be used for probe positioners utilized in high intensity light applications to test optoelectronics. Researchers printing one themselves and using hardware store fasteners can build one for under $5.

Each BYB manipulator is distributed fully assembled with four degrees of freedom: up/down (at an angle), left/right, forward/backward, and electrode angle of attack (135°). The latter can be adjusted by changing the angle of the printed parts. It comes ready to mount with four small rare earth magnets on the bottom of the manipulator (inset Fig. 1). The positioner has a total volume (without electrode attached) of 10.5 cm long by 7.9 cm wide by 9.5 cm high. Each full turn of a knob