Enhancing the capability-to-affordability ratio of a manufactuting process: The didactic case of a 3D printer

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ABSTRACT

A MakerBot Replicator 2 3D printer is nowadays a common sight in many Engineering academic departments. Affordable and conveniently sized, it helps demonstrate the capabilities of 3D printing in modest projects of homogenous static parts made out of polylactic acid (PLA). In this work, the aim is to challenge the capabilities of the printer to create (i) multicolor parts, (ii) net shape parts with movable components that do not require any assembly, and (iii) composite parts with heterogeneous materials. Objects with multicolored and movable parts were created in a single print, a knife prototype was manufactured with the combination of PLA handle and a steel blade, and a prototype for an electric fan's body was designed to fit the motor, battery, and its contacts. This sequence of projects demonstrates how complexity can arise from simple manufacturing processes to improve the capability-to-affordability ratio. The integration of the techniques was accomplished through the replication and simplification of a trap for mosquitoes. The original design comes from the Center for Disease Control and Prevention (CDC) and it includes a light to lure mosquitoes, an electric fan for specimen suction, an entrapment net, and a cylindrical encasing. The resulting design and the 3D-printed prototype require considerably fewer fasteners and part components, and thus, less assembly effort. In fact, the bulge of this system was created in a single print. These techniques result indeed in enhanced capabilities for a simple 3D printer that allow approaching real problems, such as pest control as demonstrated here.

KEYWORDS

Additive manufacturing; 3D printing techniques; composite parts; multicolored parts; movable parts, 3D printed mosquito trap.

RESUMEN

Hoy en día es común hallar una máquina de impresión 3D como la MakerBot Replicator 2 en departamentos académicos de ingeniería. Esta máquina tiene un costo modesto y un tamaño práctico para demostrar las capacidades de impresión 3D. Los proyectos académicos asociados son típicamente pequeños donde se fabrican piezas estáticas usando un sólo material, como el ácido poliláctico (PLA por sus siglas en inglés). En este trabajo, el primer objetivo fue retar las capacidades de una impresora de este tipo para lograr imprimir (i) partes multicolores, (ii) objetos con forma neta con componentes móviles que no requirieran ensamblaje, y (iii) partes compósitas hechas con materiales heterogéneos. Dentro de los primeros resultados, los objetos multicolores y con partes móviles se pudieron generar en una sóla impresión y fue posible fabricar un cuchillo sin conectores adicionales combinando PLA y una hoja de acero inoxidable. Adicionalmente, se manufacturó el prototipo de un ventilador personal eléctrico con un número bajo de operaciones de ensamblaje para añadir el motor, las baterías y las terminales. Esta primera secuencia de proyectos independientes demostró cómo se podían expandir las capacidades de este proceso simple de manufactura. La integración de las técnicas desarrolladas en esta secuencia se utilizó para abordar la simplificación de diseño y replicación de una trampa eléctrica de mosquitos, un proyecto real más complejo. El diseño original de la trampa proviene del Centro Federal para Control y Prevención de Enfermedades (CDC por sus siglas en inglés) en EEUU e incluye una tolva, un señuelo eléctrico luminoso para atraer los mosquitos, un ventilador eléctrico para succionar a los especímenes, una red para atraparlos, y un cuerpo cilíndrico para encapsular los componentes eléctricos. El rediseño resultante y el prototipo ya impreso requirieron considerablemente menos componentes y conectores y, por tanto, menor esfuerzo de ensamblaje. De hecho, la mayor parte de este diseño se pudo manufacturar en una sóla impresión. Con estos proyectos se demuestra didácticamente cómo es posible incrementar la capacidad de un proceso de manufactura sin incrementar su costo. De especial importancia es el hecho de tener un caso real como el de control de mosquitos para apuntalar tal conclusión.

PALABRAS CLAVE

Manufactura Aditiva, Técnicas de Impresión en 3D, Compósitos, Impresiones 3D multicolor, Ensamblajes con partes móviles de forma neta, Trampa para mosquitos en impresión 3D

INTRODUCTION

Printing in three dimensions is taking an important role in manufacture industry subsectors such as medicine, automotive, and electronics.[1] Additive manufacturing (AM) is a process of creating three dimensional objects by adding materials layer by layer, which is also known as 3-D printing. In addition, this technology is very useful for general purposes rapid prototyping.

The printer used in this work was the MakerBot Replicator 2, which works with fused desposition modeling (FDM). FDM is a material extrusion process used to make parts layer by layer through heated extrusion and deposition of material.[2]

This printer has one extruder, uses PLA polymer, and does not have a heated build plate. The MakerBot Replicator 2 is one of the most affordable 3-D printers in the market, so it is a popular piece of equipment in engineering departments.

The objective of this work was to challenge the perceived limitations of the 3D printer to create multicolored objects, movable parts in an object without any assembly required, and combine steel with the PLA plastic without the need of external assembly. What was learned from these three challenges was then combined to approach the fabrication of a personal fan with an integrated motor. All the prints were done at a travel speed of 150 mm/s or 170 mm/s, the filament was heated at 230°C, layer height of 0.10, 0.20, or 0.30 mm, and with 10 to 20% infill density.

PROCEDURE

The general methodology to design and create each desired prototype is shown in the process flowchart in figure 1. The ensuing sections describe the specifics of each challenge.

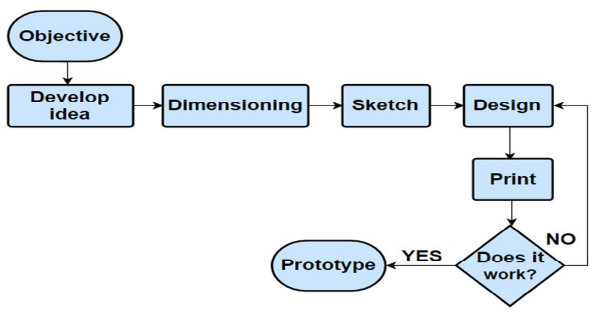

Fig. 1. Prototype process flowchart.

Multicolored and movable parts

Multicolored objects created with the MakerBot Replicator 2, which has a single extruder, was easily approached by using the function of "Change Filament" while printing an object was in process. After the filament was changed, the function of "Resume Printing" allowed the print to continue normally where it was stopped. figure 2 shows the result of this operation.

Objects with movable components created in a single print and without any assembly required is, however, a more challenging and innovative endeavor, as described elsewhere.[3] To this end, three different designs were created and attempted.

Fig. 2. Multicolored layers object.

The key to such designs is allowing gaps between the movable parts and the surrounding components through tolerance adjustment. Movable parts that are designed at a higher level from the print bed need to have a support. This can be effectively reflected in MakerBot's software for printing purposes.

The first movable object was a fan-like structure shown in figure 3a. The blades were joined in a ring that surrounds the cylinder with less tolerance. This was designed to be printed at a higher point to avoid the ring with the blades from being attached to the base. The resulting object is shown in figure 3b.

For the second object, the purpose was to print a useful object with movable parts, therefore two boxes were designed, shown in figure 4a and figure 5a. Both boxes had movable doors, however the second box was an improved design from the first box. A lock was added to the second box to test the possibility of having different movable components in the same object. To test the movable doors, pins were designed at the top and bottom corner of the doors and printed inside holes, with higher tolerance at the box's top and bottom walls. These kept the doors in place and allowed the pins to rotate freely. The lock of the second box was designed with a cylinder that crossed the door through a hole. The back end of this cylinder include a half sphere to avoid displacement and at the front end a flat bar acts as the lock. In both designs the diameter of the holes were bigger than the inside parts (pins and cylinder), to provide the gaps between components. The printed objects are shown in figure 4b and 5b respectively.

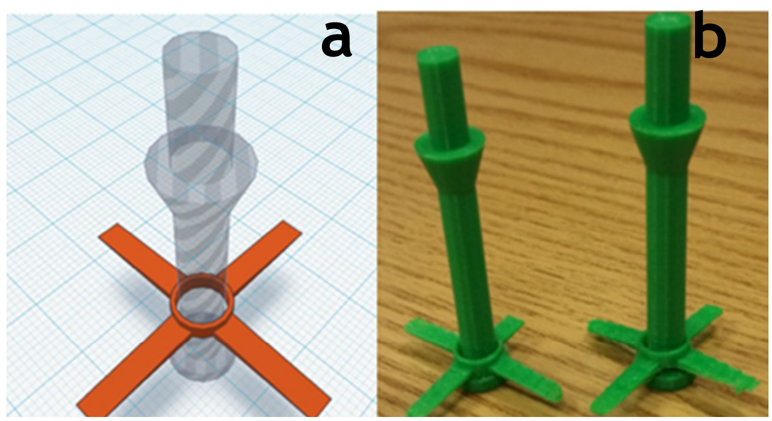

Fig. 3. Manual fan (a) CAD design and (b) prototype.

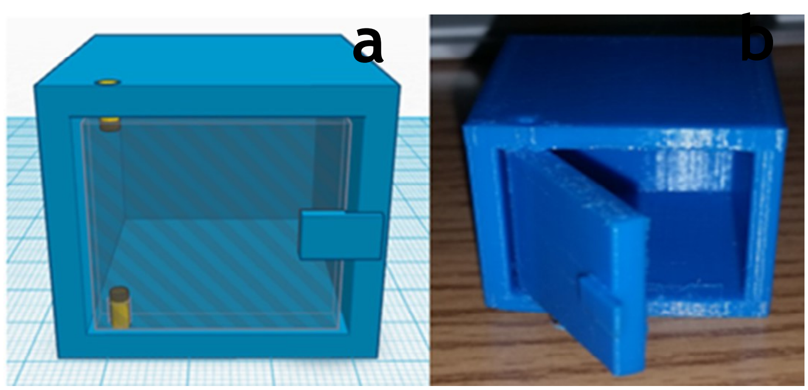

Fig. 4. Box with movable doors (a) CAD design and (b) prototype.

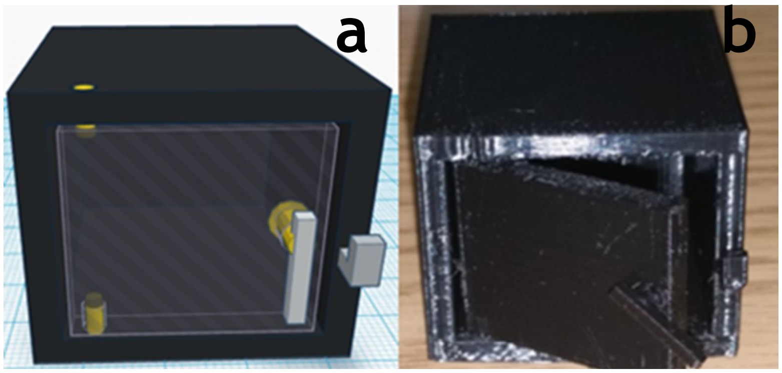

Fig. 5. Box with movable doors and lock (a) CAD design and (b) prototype.

Composite object

A combination of two materials, steel and PLA polymer, was tested by printing over a steel blade to create a knife. First, the thickness, width, and length of the blade was measured to determine the position of the blade inside the plastic handle. The diameter of the blade's hole was measured to design a pin to hold the blade inside. A portion in the center-upper of the handle was designed to place the blade. The pin helped to keep the blade in position. The printing process was paused when half of the handle was printed with the space available to position the blade, see figure 6a. After the blade was placed, the printing process was continued by depositing the material and covered the top of the blade. Some heat was applied to the blade when it was placed, the purpose was to merge the plastic and steel to avoid the blade from moving. The knife is shown in figure 6b.

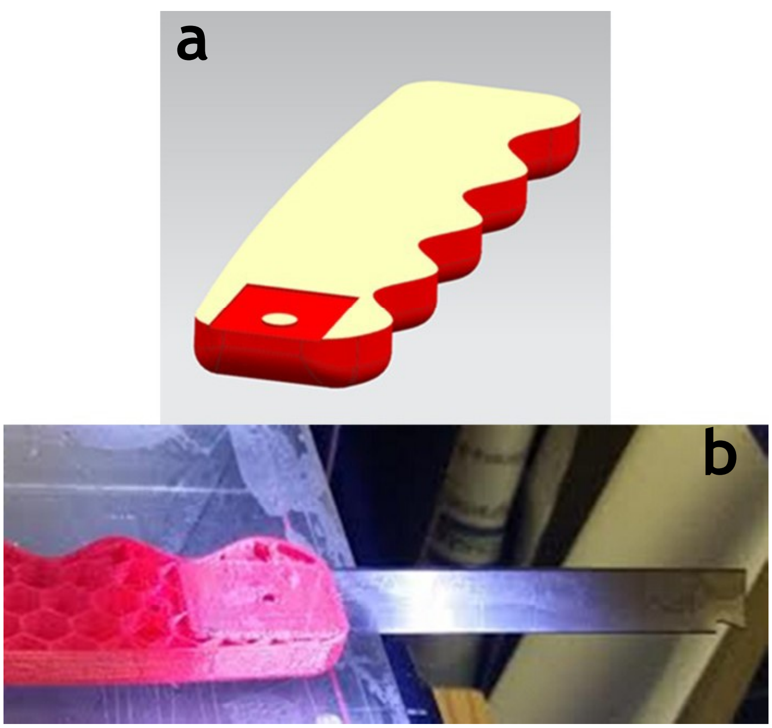

Fig. 6. Steel knife with PLA (a) CAD design and (b) prototype.

Electric fan

The previous methods were combined to create a personal fan powered by an electric motor. The dimensions of the motor and the battery were measured and it was determined that a double A battery was an adequate energy source of the fan given its affordability. The body of the fan was designed as a cylinder shape for better grip. The interior design of the fan, where the motor and the battery were placed, is shown in figure 7a. The printing process was paused when the first layer was printed on top of the motor's position to be able to insert the motor at its place, shown in figure 7b. Once the motor was positioned, the battery contacts were inserted in the holders and then the battery. The printing was continued and then paused again when the cables of the switch were settled. In the design, the only part that can be opened is at the top of the battery's position, which allowed changing only the battery. The final part can be appreciated in figure 7c and 7d.

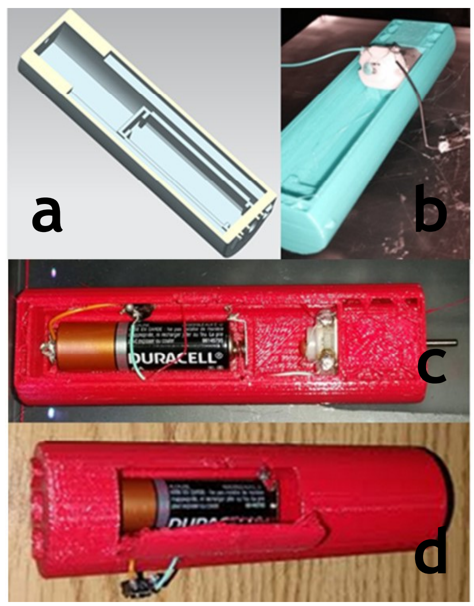

Fig.7. Electric fan: (a) CAD design, (b) placing motor, (c) interior view, (d) prototype.

CDC light trap

The Center of Disease Control (CDC) designed a light trap used as a sampling device for the collection of mosquitoes and sand flies used in arbovirus and taxonomic studies, shown in figure 8. Redesign of this kind of trap could lead to a simplified set up process through the reduction of assembly elements and fasteners. In the end, the electric fan together with a light bulb, a cylindrical body, a filter, and the top plate were combined into a single body that did not require assembly operations. The first prototype had the same parts as the original design but with a simplified process to attach the filter to the cylindrical body. Fasteners were eliminated from the filter through matching interlocking parts as shown in figure 9a and figure 9b. In the second prototype, the attempt was to integrate most parts possible into a single piece to reduce the number of components. A vertical filter was designed to support the top plate and to join the cylindrical body as shown in figure 10a.

In this last prototype, the electric fan was enclosed inside the cylindrical body. Similar to the process of the composite object, the printing process was paused around seventy percent thru the print job to place the electric fan, after which, printing was resumed.

Fig. 8. Original trap set up.

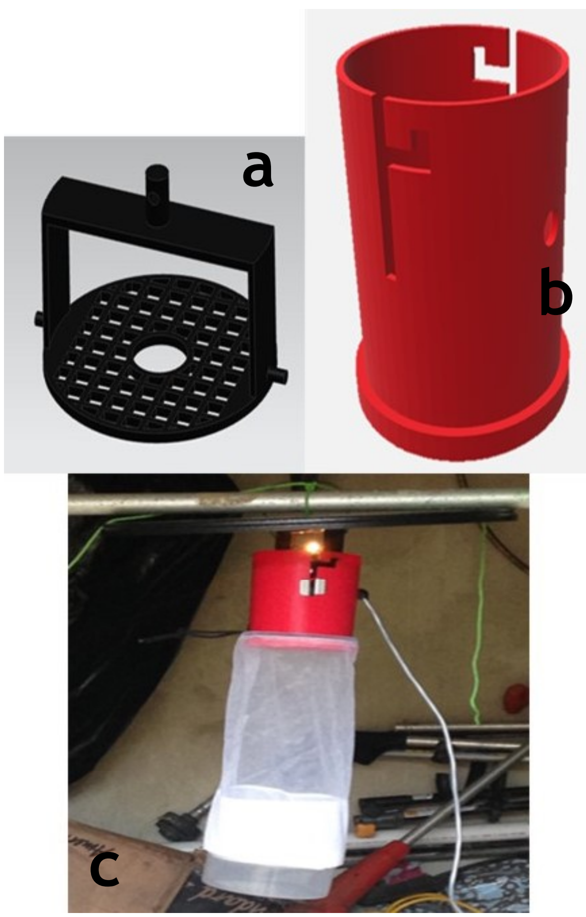

Fig. 9. First trap (a) Filter CAD design, (b) Cylindrical body CAD design, (c) Complete set up.

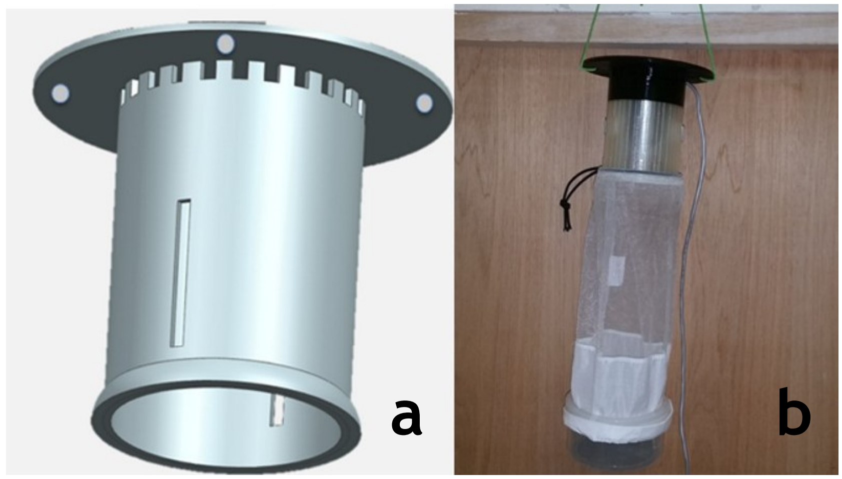

Fig. 10. (a) Second prototype, (b) Complete set up.

RESULTS AND ANALYSIS

Multicolored and movable objects

Printing objects of different colors is possible with the MakerBot Replicator 2, (figure 2). A single extruder is not a limitation to print exclusively of one color. The function of "Change Filament" allowed the user to print any object with different colors but only by layers, since the material was deposited by this pattern. The colors were mixed one at a time. The disadvantage of printing objects with several colors with a single extruder is the time consuming process of changing each filament.

In addition, an object created with this printer is able to contain movable parts without requiring any assembly. The blades of the manual fan spun freely without constraints since the ring with the blades had a reasonable space between the main parts of the object, shown in figure 3b. Also, in figure 4b and figure 5b the boxes' doors opened and closed with no difficulties between the pins and the surrounding surfaces, which demonstrated that complex geometries can contain movable parts if the design is properly made. This technique is an advantage in manufacturing because net shape objects can be produced without finishing or additional operations.

Composite object

The knife made from the steel blade and PLA polymer proved that is possible to combine materials using the 3D printer, as shown in figure 6b. The knife was successfully printed and the blade does not move or slide when cutting is done. As a result of applying heat, the blade is firmly joined with the plastic and made it difficult to detach from the plastic handle. It is certainly recommended to know how different materials interact with this technology to decide the properties of the product and evaluate the possibility of manufacturing objects with multiple materials.

Electric fan

Integrating a motor and its components in the design was successfully carried out to create an electric personal fan. The motor was enclosed with the material, which did not allow it to be removed without damaging the object as shown in figure 7c and figure 7d. It was possible to reduce the use of fasteners and avoid assemblies to arrive to the final product. To remove the motor, the object's body must be opened up. This fan is a quasi-net-shape object, since the blades must still be assembled offline.

CDC light trap

A simplified CDC light trap was achieved through the integration of the techniques applied to facilitate the set up process. In the first prototype, the interlocking cylinders reduced assembly work and time, even though the prototype was very similar to the original design. On the other hand, the second prototype requires almost no assembly since a single body trap was created. The combination of three pieces into a single part was possible through the modification of the filter orientation. Both prototypes resulted in the elimination of fasteners, and the work and time of the set up process is less with the reduction of individual components.

CONCLUSIONS AND FUTURE WORK

All the challenges proposed in this project to enhance prototyping capability with a simple 3D printer were achieved. Even though the MakerBot Replicator 2 model is a simple one extruder machine, these characteristics do not preclude the creation of complex parts as shown here: multicolored and movable parts in a single print, combination of steel and PLA plastic, and fully functional multicomponent prototypes. All of these capabilities were demonstrated in their coordinated use in the replication and simplification of a mosquito trap. The techniques developed in this work constitute a positive contribution to manufacturing and prototyping since time and cost are reduced by producing net or quasi-net objects.

ACKNOWLEDGEMENTS

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