THE NEXT GENERATION OF CRIME TOOLS AND CHALLENGES: 3D PRINTING

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3D printing technology both supports and challenges criminal investigation.

Although it is relatively new from the perspective of its appearance in criminal investigations, 3D printing technology — or additive manufacturing — is not new. It originated in the 1980s;[1] only in the past decade have 3D printers become smaller and affordable enough for the mass market. (You can purchase a basic 3D printer, which fits on a desk, for well under $1,000.) Today, this technology is widely available and relatively simple to use for both lawful and illicit purposes.

3D printers can create a variety of highly customizable objects at relatively low cost. Their applications are nearly endless. Examples of the commercial application of 3D printing include, but are not limited to, manufacturing airplane and automotive parts, footwear, and medical and veterinary prosthetics.

3D printing technology has also been used for criminal justice purposes. Crime scene investigators and forensic examiners have used it in accident reconstruction, replication of crime scene evidence, and facial reconstruction from unidentified skeletal remains.

Criminals are also taking advantage of the versatility of this technology. Among the most worrying of its illicit uses is the creation of 3D-printed guns and other weapons.[2]

3D printing technology is relatively simple to use and can help support criminal investigations. But it is also a tool for criminals, who can use the technology to print guns and other weapons and objects for a host of nefarious activities.

The technology is widely available and relatively simple to use, and criminals will undoubtedly find more creative ways to use it. As a consequence, we expect to see 3D printers and their products submitted for forensic analysis in criminal investigations, if they have not already been. Forensic examination of 3D printers and their products is challenging. Because of the newness of this technology from an evidentiary perspective, there is a lack of both forensic research and validated test procedures. This limits the ability of forensic scientists to offer definitive conclusions regarding this technology or its products.

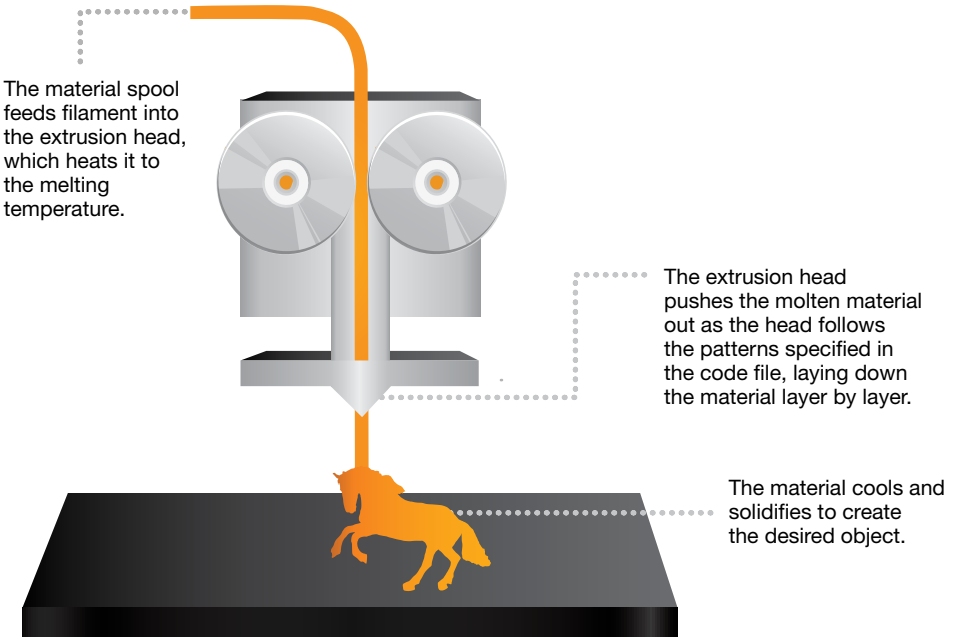
Understanding the Technology

Traditional manufacturing processes subtract materials — for example, drilling out part of the object to create holes or grinding down a steel ball bearing to achieve the desired shape. Additive manufacturing refers to the process of creating an object by adding materials, a process that all 3D printers use.

There are three general steps to creating an object by 3D printing:

- Create a 3D model (a blueprint) of the object to be printed, using computer-aided design (CAD) software.
- Translate the model into very thin two-dimensional, cross-sectional layers (slices) of the object.
- Print the object by depositing layers of a material, or materials, in two-dimensional slices until the object is fully formed in 3D.

Exhibit 1. Printing Process of Fusion Deposition Modeling



The process of printing an object with a 3D printer can begin in one of four ways. The most difficult is creating the model of an object "from scratch" using CAD software. Less difficult is developing the model using a 3D scan or digital images of an object — taken from multiple aspects — as a starting point. The easiest way to begin the process is by using an existing model. Models of a variety of different objects are readily available from several open-source file-sharing sites.

3D-printed objects are created by depositing one layer of printing material at a time in a pattern that follows the model specifications until the object is complete. This can be done using a variety of materials, the most common of which are thermoplastic polymers, photopolymers, resins, ceramics, and metals. Printing could take minutes, hours, or days, depending on the complexity and size of the model and the material used.[3]

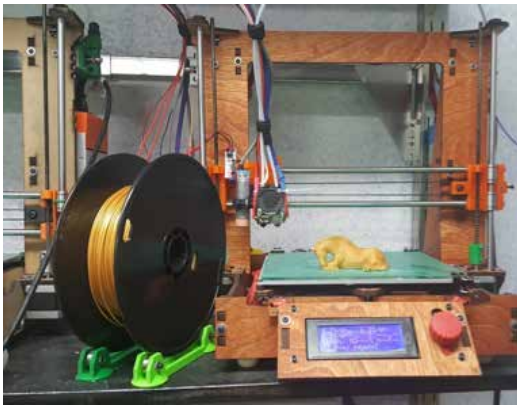
There are a number of different 3D printing processes. They vary in how the printing material is deposited and bonded together, based on the properties of the materials used. The most common process used for desktop 3D printers is material extrusion, or fusion deposition modeling (FDM). These printers use inexpensive thermoplastic filament as the printing material.[4] As shown in exhibit 1, the process is simple: Spooled thermoplastic filament is fed to a heated extrusion head, where it is heated to a high temperature and forced out of the heated nozzle as the print head moves. The material bonds and hardens as it cools. Exhibit 2 shows an example of a horse printed from an FDM printer.

Forensic Applications of 3D Printing

Criminal justice practitioners can use the technology to print replicas of evidence and crime scenes for easier courtroom demonstrations and for a more efficient facial reconstruction process. (See sidebar, "NIJ Projects Involving 3D Printing.")

Creating replicas of evidence is not a new practice; dental stone casts of footprints and Mikrosil casts of toolmark impressions are commonplace.[5] However, casting is not always practical in cases where the substrate — such as soil — quickly deteriorates or is prone to deformation. In these cases, time is a factor; 3D printing offers a solution to this challenge. Crime scene technicians can capture photographs of the impression from many different angles and then use photogrammetry software to create an accurate surface model of the impression. Using the images, they can print an exact replica — or as many as they need — as opposed to the traditional method of casting the impression directly to obtain a reverse image of the evidence.

Exhibit 2. An FDM-Printed Object



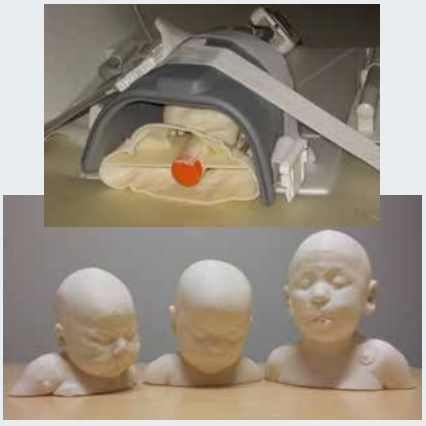
Note: Many of the parts of the FDM printer have been printed by an already completed 3D printer.

Source: Photo taken by Ruby J Chase, on behalf of NIJ.

In its first use of 3D printing, the Devon and Cornwall Police in Exeter, England, enlisted Plymouth City College to design a replica of a weapon — a broken Newcastle Brown Ale bottle — that was used to fatally stab Alex Peguero Sosa in the neck. The suspect, Lee Dent, testified that it was self-defense and that he did not realize he was holding the bottle when he hit Sosa. However, after demonstrating to the court how he held the bottle using a 3D replica of the broken bottle, it was clear to the jury that he was aware of the deadly weapon in his hand. After eight hours of deliberation, Dent was convicted of murder in 2015 for his brutal attack.[6]

NIJ Projects Involving 3D Printing

NIJ is already funding projects that use 3D printing for forensic applications. For example, the University of New Mexico sought to optimize magnetic resonance imaging (MRI) acquisition settings, receiver coil sensitivities, and subject positioning for infants, toddlers, and children. This was necessary because MRI coils are typically designed to scan parts or regions of adult subjects. The university printed 3D MRI phantoms — designed to evaluate and optimize system performance for different tissue types or physical geometries — of pediatric head, neck, and shoulders models to assess and optimize the performance of available coils. The first set of photos shows 3D MRI phantoms of a 3-month-old, a 6-month-old, and a 12-month-old child for comparison and a phantom of the 3-month-old in a small flex coil ready for the MRI.



Source: Photos courtesy of the University of New Mexico.

In another project, the University of Central Florida used 3D printing to prototype and produce a portable fluorometer for drug detection in the field (see second set of photos to the right). The spectrometer can interface with a cell phone and identify substances from a cloud-based database. 3D printing is precise enough to produce the optical paths needed for the spectrometer to function, while also resulting in a lightweight device. The use of 3D printing allowed for a rapid and inexpensive redesign of the prototype and enabled production of the spectrometer at a cost to the consumer of less than $50.

Source: Photos courtesy of the University of Central Florida.

3D printing technologies helped police understand one particularly gruesome case in Birmingham, England, and present printed body parts to the jury instead of disturbing and distracting graphic photos.[7] Convicted killer Lorenzo Simon murdered Michael Spalding in 2014, then dismembered the body, stuffed most of it into two suitcases after trying unsuccessfully to burn some of the bones, and threw the suitcases into a local canal.[8] Police recovered part of the victim's humerus from an oil drum furnace found in Simon's garden and the two suitcases filled with Spalding's body parts from the canal. Nine pieces of bone from the oil drum and the suitcases were x-rayed at different angles using 3D scanning technology that displayed the cuts on the bone in minute detail. 3D printing experts at the University of Warwick made

Exhibit 3. Humerus and Femur Prints with an FDM Printer

Note: Bones like these can be used in court to show how two pieces fit together instead of showing graphic photos.

Source: Photos taken by Ruby J Chase, on behalf of NIJ.

Exhibit 4. 3D-Printed Skull

Note: Printed skulls like this one can be used for facial reconstructions to minimize damage to the real skull.

Source: Photo taken by Ruby J Chase, on behalf of NIJ.

replicas of the bones to demonstrate the evidence to the jury, showing that one of the oil drum bones was a seamless fit with a limb found in one of the suitcases. The printed bones were used in court demonstrations, and Lorenzo Simon was convicted. (See exhibit 3 for an example of how printed bones can be used in court.)

Small items of evidence can also be printed at a large scale to show detail. Impression evidence such as friction ridge impressions (latent prints), footwear, and tire treads captured using 3D technology can be enlarged to examine specific details that may not be visible to the naked eye and can be used for courtroom demonstrations. For example, using large-scale models of two compared fingerprints that display shared minutiae may help the jury understand the evidence's significance and limitations.

3D printing is also becoming useful in facial reconstruction. In traditional facial reconstruction, artists layer clay on to a real skull until facial features are restored and then take pictures of the restored face.[9] However, this practice can damage the skull. It is also standard practice to have several artists create reconstructions to focus on facial features that are difficult to discern solely from the shape of the skull.[10] The entire process gets completed several times on the same skull, one artist at a time, with the potential for skull damage increasing with each reconstruction. 3D printing and other software systems can eliminate the need to handle the original skull beyond scanning it once (see exhibit 4). Several artists can receive the computer model of the skull and create virtual reconstructions using software programs that imitate clay reconstruction, or they can receive 3D-printed replicas for traditional reconstructions.[11] Because each artist would have his or her own skull replica, the clay does not have to be stripped and the entire set of reconstructions can be saved and compared. The use of 3D printing for investigations and court demonstrations is still new, but the possibilities and

potential applications in this area will continue to evolve.

Illicit Applications of 3D Printing

The primary concern from a criminal justice perspective with regard to 3D printing is the ability to manufacture difficult-to-detect, untraceable contraband.

The 3D printing community has an open-source mindset, and so users have access to several repository websites from which they can download a design file instead of creating their own. Of course, the industrial community and even some hobbyists prefer to patent and restrict access to their designs, but the criminal justice field is less concerned with those files. The open-source files, however, are of great concern because anyone can download and modify them. They can download and use design files and blueprints for weapons or bomb parts, regardless of their intent. An innocent object could be modified for illicit applications. The download and modification of these files is not currently federally regulated, but the State Department has proposed regulation of posted blueprints for 3D-printed firearms.[12] Also, the most popular open-source repository's terms of service state that by using the site, you agree not to collect, upload, transmit, display, or distribute any content that promotes illegal activities or contributes to the creation of weapons.[13]

Using 3D printing technology to create guns is a controversial topic; despite the controversy, there is no doubt that building a gun with a 3D printer can be done with relative ease using inexpensive technology. There is very little regulation on making and owning a 3D-printed gun, which, in turn, creates challenges in identifying parts and materials during an investigation. Users have already shown that anyone with a low-end 3D printer can download publicly available, open-source files and print the plastic parts to make a working firearm. The threat of homemade, untraceable firearms is real — a murder-suicide in 2016 in Walnut Creek, California, and a 2013 mass murder at a Santa Monica college were both committed with homemade weapons, colloquially termed "ghost guns" because they are not made with serial numbers. California recently passed a law, effective on July 1, 2018, that will require a person who manufactures or assembles a firearm (including 3D-printed guns and other homemade firearms) to first apply to the California Department of Justice for a unique serial number or other identifying mark.[14]

In addition to creating difficult-to-detect, untraceable contraband like firearms or bomb parts, criminals are using 3D printing for other illicit purposes, such as to manufacture counterfeit parts that can be used in fraud cases. In fall 2014, Spanish and Bulgarian authorities infiltrated an organized crime ring that was committing credit card fraud by printing the equipment to manufacture fake plastic card slot bezels installed on ATMs and point-of-sale terminals as "ATM skimmers." The criminal network was operating in Italy, France, Spain, and Germany; authorities made 31 arrests and confiscated more than 1,000 devices.[15]

New printer technologies debut regularly. Printing materials such as carbon fiber, titanium, and other metals are becoming more popular, and printers capable of printing in metal are becoming less expensive.[16] The law enforcement community is concerned about people printing metal objects such as explosive devices, weapons, or other parts for illicit purposes. In addition, criminals who enter the country illegally and need to acquire weapons or other equipment for illegal activity can use 3D printers — this may be difficult for law enforcement to trace.

3D printing may also offer a way to successfully bypass a number of biometric security measures. Materials like thermoplastic polyurethane and nylon remain flexible when printed and could be used to print a fingerprint or a handprint. This includes friction ridge detail and blood vessels underneath the "skin," so warm blood substitute can make the fake print warm, as if it is living tissue. It is also feasible that a desktop printer could print the pattern of blood vessels in the eye to bypass retinal scanning. The applications for which criminals could use 3D printing are limited only by their creativity.

Forensic Investigation of Crimes Involving 3D Printing

Investigations involving 3D printing are likely to include collection and analysis of digital media, such as CAD files, and physical evidence such as printed objects, printers, and printing materials. Computer forensics can play a pivotal role during the investigation of crimes involving 3D printers; however, here the focus is on the analysis of physical evidence.

The objective of most forensic examinations involving physical evidence is either to analyze an item to determine its origin or to compare the item with materials seized from a known source to determine if they share an origin. The analysis of most physical evidence includes identifying class characteristics that may be common to a manufacturer or a specific model, and individual characteristics that are unique markings imparted on an item from a specific 3D printer.

Forensic scientists can use visual, microscopic, optical, and trace-chemical methods to analyze and compare physical evidence related to 3D printers; these same methods are commonly used to link questioned documents with inkjet printing devices.[17] Although forensic analyses are available to analyze metals, plastics, resins, polymers, and a host of other trace materials, there is very little research on the analysis of 3D-printed objects to evaluate individual characteristics imparted from the printer. For example, tracking a printed object back to an individual printer or a spool of thermoplastic filament (or other printing material) would be extremely helpful during an investigation. There are also other trace-chemical examinations to consider, such as analyzing finishing products (e.g., paints or dyes) that may have been used, or pollens and dust caught in the printed object as the printing material dried.

There is great potential to recover latent prints and DNA from 3D printers (and their components) and printed objects. Understanding the type of surface of a 3D-printed object is critical to recovering a quality latent print; forensic scientists can use different chemical methods to recover prints, depending on the surface type. Given that 3D-printed objects may have different pliability, porosity, or other physical variations, we need more research to optimize latent print recovery. Finally, DNA analysis can be a powerful forensic method for linking a suspect to an object, but once again, more work is necessary to understand and optimize recovery of DNA evidence from the various materials available for 3D printing.

A Need for More Research

Over the years, 3D printing technology has become inexpensive and easy to use, allowing the public to

Exhibit 5. 3D Printing Striations

Note: This close-up shows the striations present in all 3D-printed objects.

Source: Photo taken by Ruby J Chase, on behalf of NIJ.

have access to this advanced manufacturing process. The criminal justice system is using 3D printing in evidence replication, facial reconstruction, crime scene reconstruction, and court demonstrations. While 3D printing is a tool that can support investigations, it is also a tool for criminals, who can use the technology to print guns and other weapons and objects for a host of nefarious activities.

A completed FDM object does not require post-treatment unless the hobbyist uses support material in the printing. With the FDM technique, one cannot deposit printing material without somewhere to deposit it, so some objects require support material to be printed underneath overhanging parts of the object.[18] Users will need to remove the support material to obtain the final, desired object. Users can also sand, polish, and paint the object, although the objects are difficult to finish in this way because of the striations that the layers produce as they are deposited (see exhibit 5). Each change made to a printed object introduces individualities that can be analyzed, but how the object changes with each type of post-treatment has not been studied.

The thermoplastic filament used for FDM printers includes, but is not limited to, ABS (acrylonitrile butadiene styrene), PLA (polylactic acid), PVA (polyvinyl acid), PC (polycarbonate), TPU (thermoplastic polyurethane), nylon, and PETG (polyethylene terephthalate), which is a version of PET modified specifically for 3D printing.[19] Forensic scientists can conduct trace-chemical examinations on all of these thermoplastics, but there is very little research on the forensic value of this type of analysis and on whether forensic scientists could make conclusive statements about the origins of a 3D-printed object.

Forensic capabilities are currently lagging because there has been limited exposure to crimes involving 3D printers. There is also little research on how to associate the materials and objects with a specific 3D printer or class of printers. For example, materials such as PETG, copper-infused filament, and wood-fiber-infused filament are being designed specifically for FDM 3D printers; research could help identify and forensically compare these materials. 3D printers and the objects they print, as well as the associated software and files, are likely to have evidentiary value with a greater understanding of this technology.

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For More Information

To learn more about NIJ's forensic science portfolio, go to NIJ.ojp.gov, keyword: forensic science.

This article discusses the following grants:

- "Investigation of Post-Mortem Magnetic Resonance Imaging for the Detection of Intraneural Hemorrhage," grant number 2013-DN-BX-K004
- "Transition Metal Cluster Compounds for the Fluorescent Identification and Trace Detection of Substances of Abuse," grant number 2012-R2-CX-K005
- "Low-Cost Handheld Spectrometer and Cloud-Based Data Analysis for Improved Identification of Substances of Abuse," grant number 2015-R2-CX-0035

Notes

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