Abstract

3D scanning of biological structures will revolutionize production of personalized medical equipment. This technology has already been applied to the production of casts and structures used internally for surgeries. This project explores the feasibility of designing a finger splint from commercially available 3D scanning technologies. Creating a splint of other medical devices that can be produced form the home will increase public health by increasing the availability of medical equipment for those who may not have access to necessary medical equipment. Technologies such as this can be extended to other medical equipment as well, such as limb braces that are used to support developmentally challenged individuals. This study compares current scanning technologies, as well as suggests a design for an easy to produce finger splint.

Background: 3D Printing Today

3D printing is a specific field of additive manufacturing. 3D printing revolves around a robotic apparatus that controls the location of a jet that releases any sort of liquefied, but rapidly solidifying material, in a specific pattern. The 3D printing technology is incredibly versatile both in form and material. Virtually anything can be 3D printed, as long as the proper file is generated, anything that can be imagined can be 3D printed. This technology is most commonly used with plastic polymers, though metal, cells and sugars are other materials that the 3D printing technology is currently compatible with. The 2010s have already proven to be a time for marked growth in the availability, versatility and practicality of the 3D printing technology. The remainder of the decade will likely continue or exceed the trend of the first half of the decade.

Currently, the most common material that is used in 3D printing, both in industry and in personal use are fused deposition modeling (FDM) thermoplastics. FDM thermoplastics are a general category of many types of plastics, all of which generally are very durable, and are very similar in strength to injection molded versions of the same material. Because these materials have very similar strengths to their injection molded counterparts when 3D printed, these materials make printing a viable alternative to traditional manufacturing methods (Materialise 2015). On the cutting edge of common 3D printing materials, is the FDM thermoplastic ULTEM 9085. This plastic, in addition to being strong and lightweight like the other FDM thermoplastics, has been
rated as flame retardant (Materialise 2015). This material, because of its flame retardant characteristics, can further the versatility of 3D printed materials to include construction and components for laboratory testing (Materialise 2015). These materials have a wide range of applications, from home printing of small replacement parts to large industrial manufacturing pieces.

Currently, the price of 3D printers is slowing the growth and development of the technology as a whole. Most available to the consumer is the MakerBot printer line. The company offers three products, the mini replicator costing $1,375, the standard replicator costing $2,899, and the replicator Z18 costing $6,499. These printers are also limited in the size of the object that they can print (MakerBot 2015). The mini replicator can only print within a space of 10x10x12.5 cm and the largest of the commercially available MakerBot printers is confined to a 30x30.5x45.7 cm volume (MakerBot 2015). These limitations in the commercially available products are still a major road block for some interested in 3D printing. But, prices have fallen considerably since the commercialization of 3D printers from $20,000 to approximately $2,000 (Bilton 2013). 3D printer prices may potentially drop even further to around $100 thanks to the Peachy Printer, a product of an independent designer (Allen 2013).

3D printing is a constantly evolving field that is growing at an exponential rate. With new printable materials being developed rapidly, and interest in the technology growing, 3D printing is taking the manufacturing world by storm. The largest limiting factor is the price of the machinery, and as time passes, the prices are falling and new methods of 3D printing are being developed, 3D printing may be the most useful and widely used technology since refrigeration.

Project Introduction & Methodology

3D printing in the medical field has taken the media by storm. From printing organs from cells to printing prosthetic limbs, 3D printing has many applications in the medical field. Another application of 3D printing is personalized casts. Deniz Karasahin a Turkish student designed a cast that is readily printable, and remedies many of the issues associated with traditional casts. Traditional casts are bulky, heavy, smelly, and limit the users exposure to water (Karasahin 2013). Karasahin's product, named the Osteoid (Figure 1), is lightweight, comfortable, allows the wearer to have more exposure to water, and is neither itchy nor smelly (Karasahin 2013). Additionally, the Osteoid can integrate with a low intensity pulsed ultrasound apparatus (LIPUS). Ultrasound has been shown to increase the rate of bone healing by up to 80%. This cast not only allows for the wearer to be more comfortable while also recovering at a much faster rate. To produce a more tailored cast to the individual, 3D topographical scans of the affected area can be used.

From these scans, the topographical geography of the human body can be scanned,
producing a three dimensional model of the portion of the body that is desired. A recent study by Jing Tong et al. outlined specific methods to take a 3D model from a scan and improve it to a cleaner image (Tong et al. 2012). Though 3D scanning, better 3D printed casts can be made that can be produced to be personalized to the individual injury.

Casts and finger splints are often bulky, heavy, smelly and uncomfortable. In the light of the recent development of the Osteoid cast, 3D scans of the tissue above a broken or injured bone can be used to produce more comfortable and better fitting cast or splint. The product will be focused on finger splints rather than full broken arms or wrists. Finger splints are essentially a metal board that has a foam cushion between the metal and the finger. These are bulky, uncomfortable and do not respond well to being wet. A 3D scanned and printed alternative can be designed to be more streamlined, and comfortable as well as being water proof.

The splint will be designed in a similar way to the Osteoid cast. From a 3D scan of the affected finger, a casing of the finger will be generated. These scans will be generated using the 3D sense commercially available portable scanner and the 123D catch 3D scanning android application. Organically shaped breathing holes will be designed into the finger cast to allow the splint to be breathable and dry rapidly. The finger hole will also have an expanded, extended bottom palate in order to keep the finger immobilized as a splint is supposed to. The splint will be printed as a single piece, and will be tailored to the individual. The material will have to be either medical grade plastic or hypoallergenic material.

Design of the splint will not be without difficulties. Generating a precise scan of a small structure will be difficult for two reasons. The scanning technology available has difficulties detecting small structures and the boundaries of the generated 3D structure sometimes are not crisp. Ensuring that the materials will also be comfortable and hypoallergenic is another major concern in the design of the splint. Finally, securing the splint to the patient may also prove to be problematic. The simplest solution to affixing the splint to the hand is the use of medical tape. Medical tape however, can
be uncomfortable. If the splint can be designed tight enough to remain on the finger, but loose enough to allow blood to circulate, the problem of fixing the splint to the finger will no longer be an issue.

Figure 2: Preliminary sketch of 3D scanned and printed finger splint. The design indicates that the finger will be scanned and a 3D file will be generated of the finger. A tight fitting cast will be designed with irregularly shaped holes to increase the stability of the splint.

Project Results

In order to design the most accurate 3D printed finger splint to the human hand, a 3D scan of the finger had to be acquired. The most difficult part of designing the splint was recording a scan that was of a high quality and was continuous. Using the 3D sense 3D scanner proved difficult to use as the scanner had difficulty detecting the hand of the subject. Another difficulty using the scanner was that it was difficult for the subject to keep their hand still and steady.

Another scanning technology, cell phone 3D scanning was used to attempt to capture the 3D surface structure of the human finger. The 123D catch app was used as a commonly available 3D scanning app. This scanning method did not produce a viable scan either because the software would not compile the multiple images into a single 3D scan file.

The splint had to be designed around a set of linear measures of the human finger. The splint was designed around the human index finger. Measures of finger length, width at the tip, first, second and third knuckle. Finger height was measured at the tip, and first, second and third knuckle. The finger was measured to be four inches long. The height of the finger was measured to be 7/16 in tall at the tip, 9/16 in at the first knuckle, 13/16 in tall at the second knuckle, and 1 in tall at the first knuckle. The finger
was measured to be 5/8 in wide at the tip, 5/8 in wide at the first knuckle, 3/4 in wide at the second knuckle, 9/8 in wide at the third knuckle.

The splint was designed to be a board with a semi-circular encasing that is designed to hold the finger in place as well as preventing bending and lateral motion of the finger (Figures 4 and 5). The board was designed longer than the length of the finger so it would brace itself against the fleshy portion of the palm underneath the first knuckle. The corner and tip of the splint were rounded in order to prevent irritation of the skin, and catching on everyday materials.

Figure 3: Side View of printed finger splint designed using basic measures of the human finger. The measures were height of the finger at the tip, first knuckle, second knuckle, and third knuckle, width of the finger at the tip, first knuckle, second knuckle and third knuckle and over all length of the finger. The splint was designed to be slightly longer than the actual length of the finger to extend to the fleshy part of the palm, isolating motion.

Figure 4: Front view of printed finger splint. The remainders of the center supports are still visible from this view. The end of the splint presented to the viewer is the front of the splint, where the fingernail will extend from the splint.

The splint was printed in the unintended orientation, with the board portion of the splint on the bottom. Because the board was printed as the foundation, the semicircular encasing designed to hold the finger in place needed supports to be printed. This did not allow for insertion of the finger into the splint. When the supports were broken off,

Figure 5: Top view of the broken finger splint. The weakest portions of the splint were the edges that fractured off of the splint upon use. The area of fraction was only secured by one filament, and may have been damaged upon removal of the supports. This image also clearly indicates that the supports were not completely removed from the splint.
there was still some residual plastic from the supports, which was jagged and painful upon attempt to apply the splint. The splint was also printed thinly at the apex, which caused the semi-circular encasing to be flimsy and break (Figure 5).

Discussion

Using a 3D scanner to capture the human form is a technology that is still developing. Scanning an organic structure is difficult for many reasons. One of these reasons is that the scanner needs improvement detecting organic structures that have many different shadows. The 3D sense 3D scanner is a hand held laser scanner that captures the 3D structure of an object using two digital cameras and an infrared (IR) sensor. The cameras are used to capture the colors and images of the 3D structure and the IR sensor captures the surface structure. These functions do not work well with small and heavily shadowed structures, such as the human finger.

Another limiting factor for the 3D sense hand held scanner is that it is tethered to the computer by a cord. The cord limits the motions that are possible with the scanner. It is also difficult to ensure that the cord is not captured in the scan, in order to produce a clean scan of the object.

Another major limitation of the 3D sense scanner is that the individual cannot scan their own hand or finger without losing tracking of the finger. The scanner has to be about 2 feet away from the object in order to identify the object. It is impossible for a single individual to both keep the scanner at a consistent distance and location and scan their hand. This requires a second individual to be present to scan the finger for the cast.

The 123D catch scanning app uses serial photographs surrounding an object to generate a 3D shape of an object. Any object that can be photographed from all angles can be scanned with the 123D catch android app. The use of photographs is both the strength of and weakness of this method for 3D scanning. Because the app only relies on photographs, all that is required is a cell phone camera. Because only a cell phone is needed this method of 3D scanning is portable and can be used in any setting, with no power cords or battery concerns. This method does require an internet connection to process the 360° images of the object into a 3D file.

This app is great in theory, as it claims to be able to scan any object that can be photographed from all angles. However, the apps use of the phones gyroscope to determine the position of the image being recorded is very difficult to engage with. Even if all of the images that the app requests are taken, the app will often not be able to convert the images to a 3D file due to photographs that do not line up adequately or because there is too much...
shadow on some of the images. Because was so
difficult to produce a good scan from this app, the
producing an original scan was not feasible. One
useful feature of this app however is that there is a
open forum for posting successful scans. This is
where a successful scan had to be aquired.

Finally, the 123D catch app is also difficult
to use without aid of another person. Even though
there is no minimum distance, interfacing with the
application and the gyroscope in the phone while
attempting to scan an individuals hand is a task best
left to two people.

Both scanning techniques face severe
limitations to their usefulness at their current stage
of development. These major limitations are their
fidelity to the actual object being scanned, the ease
of producing a high quality scan, and the
requirement for two people to capture the scan.
Additionally, creating a scan of a living organism is
difficult because both methods require a perfectly
still target in order to produce the highest quality
scan. This may have been the largest limiting facto r
for this project. To remedy this, perhaps creating a
machine that both isolates the hand and can move
the scanner in a uniform pattern to create a full scan
can be implemented to create higher quality, less
motion blurred scans. However, implementing a
machine such as this detracts from the point of being
able to scan a finger or hand and create a splint
without leaving the home.

It was determined that the 3D sense scan was
the better of the two methods, and a splint was
attempted to be constructed around the model.
Rhinoceros 5 was used as the 3D modeling program.
Though the program was designed to create curved
surfaces as well as flat, conforming to the 3D scan
was near impossible due to the low quality of the
scan. Because none of the fingers adequately
represented the form of a human finger, the idea that
a splint based off of conforming to the human finger
surfaces would not be possible in the given amount
of time.

Because the conformation method was no
longer possible, designing the splint shifted to a
simpler design, based off of 9 measures taken from
the human finger. These measures were height of the
finger at the tip, first knuckle, second knuckle, and
third knuckle, width of the finger at the tip, first
knuckle, second knuckle and third knuckle and over
all length of the finger. These nine measures were
used to ensure that the splint was the correct length
and height to allow for the finger to be inserted into
the splint comfortably but have a snug fit. All height
and width measures were increased by 1/8 in order
to allow for some variation in the finger shape. The
splint was designed in sketchup and was exported to
the makerbot desktop for printing.

Following printing, the first issue with the
printed splint was that the splint had been printed in
the incorrect orientation and the supports that are
automatically added to the print had been added to the finger cavity of the splint. In order to use the splint, the supports had to be completely removed. Removing the supports from the inside of the splint was difficult and the supports were not fully removed from the inside. What was left was a jagged row of plastic that stuck out from the bottom and top of the interior of the splint. This made it very unpleasant to put on the splint. This issue is easy to fix however, as the splint can be printed on end and there will be no supports added to the interior of the splint.

Another issue with the splint is that the top portion of the enclosed area was printed very thinly. This made the top portion of the splint flimsy. Upon use of the splint, the top portion of the splint began to crack off and eventually broke off from the main body of the splint. The splint would have been more durable had the splint been designed to be thicker near the apex of the encasing portion.

In addition to being easy to produce in the home, one of the main goals of this splint was to be designed so that it would stay on without the use of tape. This was a success, as once the splint was on, it would stay on fairly strongly simply because it fit so tightly. The sizing of the splint was appropriate that once the residual supports were completely removed, the splint would fit comfortable and tightly.

Moving forward, given more time, attaining a higher resolution 3D scan of the finger would be ideal. The current state of 3D scanning makes it very difficult to get a high fidelity scan of an anatomical structure without using medical grade scans, which are very expensive. Once the scan is at a high enough quality, Rhinoceros 5 will be a much more useful tool that will allow for conformation of the splint more readily to the hand. For now, it appears that simply purchasing a splint from a drug store is the most economical means of acquiring a splint for an injured finger.

**References**


