Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications
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Greetings everyone, welcome back to part 2 of our lecture on 3D printing as part of the NPTEL topic on microsensors, implantable devices, and rod surgeries for biomedical applications. Let us quickly revisit what we discussed in the previous lecture. We briefly covered an introduction to 3D printing, including what 3D printing is, how it can be done, and the different ways in which 3D printing can be performed. We also discussed what an additive manufacturing process is. We discussed the history of 3D printing, mentioning that Chuck Hull developed the first 3D printer around 1986 and introduced the technology known as SLA, which is still widely used today. Following that, towards the end of the 1980s, new technologies like FDM and SLS were developed. In general, we discussed a brief history of 3D printing. We also covered the differences between subtractive manufacturing and additive manufacturing.

So what is subtractive manufacturing? It removes material from a large block of the same material, such as wood, plastic, or metals. We remove materials from a parent block to create the desired object. This is what subtractive manufacturing is. The removal of material can be done through drilling or milling. We then moved on to discussing 3D printing and how a 3D printable model can be created. There are different mechanisms.

First, we can make a model from scratch. We have 3D printing or 3D modelling software like SolidWorks, Solid Edge, Blender, or similar tools, and we use these to model our objects. Once modelled, we pass the design to a 3D printer. Depending on the type of 3D printer used, it will manufacture or create the object, which then undergoes post-processing, either by machines or manually. The final object will be exactly as modelled in the CAD software. That is a general introduction to 3D printing.

We also discussed the workflow, covering the different methods or mechanisms to generate a 3D model. One method is 3D scanning. If a physical model already exists, it can be scanned using a commercially available 3D scanner to create a 3D model or a replica. Another way is to rely on CAD software to create the model, or you can use a photo scanning booth where the object is placed and multiple images are taken simultaneously. These images are then stitched together to form a 3D model of the object inside the booth.

Next, the file is sent to slicing software. Before slicing, the file needs to be converted to an STL or mesh format so that the slicing software can split it into layers, which the machine can then print. Slicing software is machine-dependent, meaning it prepares a program tailored to the specific machine, enabling it to print the object. We also discussed different 3D modelling software, including SolidWorks, which is an industrial-level 3D modelling tool, Blender, which is free, and Fusion 360, which offers a free version for students.

There are many software options available online, both free and paid, that can be used either offline or online. The choice of software depends on your needs. We then discussed 3 to 4 different types of 3D printing technology. One is Fused Deposition Modeling (FDM), which is widely used because it involves a roller with filament, a wire-like material, that is fed into an extruder. The extruder heats and melts the filament, depositing it onto the print bed. Based on the sliced file or G-code sent from the computer to the machine, the melted filament is deposited on the print bed, and a finished object is produced. This is a basic printer, but there are more advanced models, including 3D metal FDM printers. This type of printer is among the cheapest available on the market. Some printers can support multiple filaments, allowing up to 10 colours to be used during printing.

We also discussed three important types of FDM 3D printers: Cartesian, Delta, and Core XY 3D printers, covering their advantages and disadvantages in the previous lecture, so I won't repeat that here. Another type is the SLA printer, which uses resin as a raw material and a UV laser to cure it, producing a solid object from a liquid photopolymer. Different kinds of SLA 3D printers exist, including industrial and desktop models. Importantly, every SLA printer requires a post-processing mechanism, which can range from a bucket of IPA to a UV sheet, or even sunlight, to cure the printed object. However, for industry-accepted mechanical properties, specialized post-processing machines like washing stations and UV curing chambers are necessary. The choice depends on the desired mechanical properties of the resin.

Next is the SLS printer, which uses powder as a base material and a laser light to sinter the powder into a solid mass. A mirror deflects the laser over the print bed, solidifying the powder. This type of printer also requires post-processing, such as removing excess powder material from the printed objects. These are some different kinds of SLS 3D printers, which, like SLA printers, require post-processing.

Now, we will move on to discussing different types of 3D printers that we did not cover in the previous lecture.

So yeah, first we will check about the laminated object manufacturing technique. Here we will be using a material roll, so like here we will have a roll of material, which is adhesive-coated laminated sheets, okay? So this roll of material is an adhesive-coated laminated sheet, which we will put on our machines, and this will be given to the print bed through a feeder, okay? So this feeder you can call it a conveyor system or something like that. So this feeder will push the laminated sheet to where we require our object to be printed. Once this laminated sheet has gone through the feeder, there will be a laser head, okay? This laser head will cut those laminated sheets based on our requirements; it will cut those laminated sheets exactly how that layer should be, so all that information will already be sent through the printer via the slicing software. So then, once this laminated sheet is here, our printer will cut, or our laser system will cut those laminated sheets. The sheet itself will have an adhesive coating, so it will stick onto the already or pre-placed object, so it will be printed on or pasted onto the already placed objects. Like that, this roller will continuously feed paper to the printer, and it will continuously form new objects, okay? This laser, this head, and this feeder will also have an inkjet head, so it can spray different colours on that laminated sheet, so you will get a very good, high-definition colour printout from this printer, okay? Then, what about support materials? This paper itself will act as a support material, and once the entire printing is done, you can simply remove the printed object from the base or printed object from the print base and then remove the support material exactly like how we do with our FDM printer, okay? These are some different kinds of adhesive laminated sheets that we can use in these kinds of printers, okay? Then we will see some available laminated object manufacturing machines. These are two kinds of LOM 3D printers. You can see the rollers here, which will be supplied to this print head or feeder. This will push the paper, and here you have the laser system, which will cut the laminated sheets, so you will have different layers of paper stacked one over another to get a proper 3D model, okay? Let me zoom in a little bit. You can see a LOM manufactured, LOM printed object. You can even see the layer lines, and it is a truly coloured object. You can get endless, millions of colours in dynamic range in these kinds of printers, so that is one of the most significant advantages of LOM manufacturing machines, okay?

Let me zoom back, sorry, okay? So now we go to binder jet printing. What is binder jet printing? It has the same powder bed as we discussed in our SLS printing, okay? It also has a powder bed, but what we discussed in SLS printing is that it has a laser to sinter powder to form a solid mass, okay? In the SLS printer, we have a laser source that will be focused on each area, so we will have a solid mass. But instead of a laser, a binder jet uses adhesive binders or adhesive materials, which will be sprayed over the powder bed to get a solid mass, okay? So here you will see liquid binders sprayed through the inkjet printer. It will be sprayed through the print heads onto the powder, okay? So your print head will have the ability to move in the x and y directions.

So this will move, covering the entire area of the print bed, and this will deposit liquid binders over the powdered base material. These binders will hold those powders together, okay, thus forming a solid mass, and after each layer is printed, exactly like in an SLS printer, this build platform will go down by around 100 microns or 50 microns. Then again, there will be reservoir powder. This reservoir powder will have a powder roller, which will again fill a very thin layer of powder over the already printed material, okay? That is how binder jet printing works and this printer also has the option where no support is needed because the powder itself will act as a support material, okay? That is one of the main advantages, as well as it supports fast printing. So unlike laser sintering and all, this printer has high speed, as well as it also supports colour printing. So that is the major advantage of binder jet printing, okay? There are a variety of powders or materials that can be used in binder jet printing.

These are listed here; you can just go through them. Now you can see a commercially available binder jet printer here, and next to that picture itself, you can see how the binder jetting process works, okay? So this will—I strongly believe—give a clear picture of how the printing is done. You will have minute holes in micrometre levels, in your print heads. This has individual controllability—each print head has individual controllability—and this will jet binders, which means it will eject your adhesive liquids into the powder, okay? You can see that, and some holes are not open; those will be controlled according to how we need our printer how we need our object to be created or how we need that particular layer to be, okay?

That is how binder jetting works. You can see a liquid stream, which is adhesive liquid, okay? So the next one is polyjet printing. In the binder jet, we see a base powder material, and we spray binders, spraying adhesive liquid over the top of that powder material, resulting in a solid mass of an object. We will get what we designed in our 3D modelling software, okay?

In polyjet, how it works is it has a jetting head; it has a print head, and those print heads will spray liquid photopolymer, okay? We have seen what photopolymer is in an SLA printer, where we have a resin tank, and we used to store resin in that vat tank, okay? Here, resin or photopolymer is stored inside the jetting head, which is supplied through some resin reservoirs. This will spray photopolymer onto the print base, and immediately after spraying, it will be cured by a UV lamp, okay, UV light. So these photopolymers are very reactive to UV light.

So once they come in contact with UV light, these photopolymers immediately solidify. So when it is in the print head, it will be in liquid form, and once it comes in contact with UV light, it will immediately solidify, okay? That is how polyjet printing works. So you will have a jetting head, and this jetting or print head will spray photopolymers onto a base or above the already printed layer, once it touches that part, it will immediately cure or immediately solidify with the help of UV light, which is attached to the print head itself. This print head also has two-axis mobility in the x and y axes, and like in every printer, this one also has a z-axis, which will lower by a certain level once every layer is printed. So this is how polyjet printing works.

So the most significant advantage of polyjet printers is that they can produce high-quality prints and that too in multiple colours, okay? Since these photopolymers are mixed, as we see in our normal 2D printers, they can reproduce millions of colours, okay? These will be high-detail prints; it will be really difficult to see the layer lines. That is the major advantage of polyjet printing, which can be used in the medical industry and all. You can see some of the most common materials used in polyjet printing, of course, rigid photopolymers and flexible resins. Flexible means that once it is printed, you will have a flexible material in your hand, and then transparent, and you can even print some biocompatible photopolymer. So once it is printed, you can use it in biomedical applications, okay? So that is how polyjet printing works.

Now let us see some of the polyjet printers and some of their printed parts. This is one of the commercially available printers, and here you can see a printer in live action; this is just a photo. You can see a print head, and near the print head itself, you can see UV light; it is white light. This will just denote that the UV lamp is on. So UV light is harmful to us, and it is very difficult to see; it will be in that blue spectrum, okay? So there will be white light to make sure that the UV lamp is on; it will just denote that the UV light is on, and it is not safe to go near it, okay? In the next picture, you can see some polyjet printer-printed parts, okay?

So you can see the details on those parts it is very accurate and it is very much detailed as you can ah let me just try to zoom in once again. I hope you can see the see those pictures. So see you can see those ah like ah bottles and everything and you can see how much accurate or how much in detail a poly jet printer can print part. It is used in biomedical applications where a surgeon needs to have a real-world look at how a patient's organs look and there are multiple other applications too just second ok. Now we go to digital light processing.

Digital light processing ah in that kind of printer we will be having a UV LED. These LEDs are UV LEDs and these LEDs will be ah like pass through a like ah will be in a prism kind of chamber and then on top of that LEDs we will be having an LCD screen ok. So basically these UV LEDs will act as a backlight to that LCD screen. So ah once this ah UV LED shine you can only ah and if you are looking in front of that LCD screen you can only see parts whether there is no image on that LCD screen. I will explain ah more about this thing in the coming slide, but just get a basic idea of this thing.

And then you will be having a print head on ah like below this print head every part will be printed and once each layer is printed then the print head will move up by a 50 micron 100 micron depending up all depending upon what resolution you give and then next subsequent layer will be printed beneath an already printed layer. So this is how DLP printers work. So I hope you understand this thing. It is a little tricky. You will be having a UV LED and those UV LEDs are shined towards an LCD screen.

Different types of resolution LCD screens are available nowadays even 12k resolution LCD screens are available on DLP printers which will give you high detailed surface finish for the printed parts. So these LEDs shined a light on the LCD screen and this LCD screen will form an image based on what that layer needs and if there is an image that image will be negative ok that image will be negative image and all other areas will be like other than the area where there are no images LCD screen will allow light to pass through it because let us consider sorry consider this as LCD screen and if I need to print a circle with a like a cylindrical object then this will be the thing and here LCD screen will be black and it will only allow light to pass or light to escape through this region. So this will solidify the resin layer just above that that ok. So here you can see one such DLP printer and next to that you can see the actual process. So here a square is projected on that LCD screen and you can see light is escaping through these areas ok?

So light is escaping through these areas. So the printer will or the LCD screen will allow light to escape through that area or only through that area and something like this shape will be formed here in this vat. So just after that, you can see an image of jewellery that is not jewellery it is a printed part mostly by wax material. So you can place this kind of highly complicated design ring on a moulding sand and you can pour molten gold or silver or whatever you want and then you can get golden or silver jewellery exactly like this. So this is the major use of this kind of DLP printer because it is much cost efficient than SLA printers.

So this is the biggest advantage of DLP printers. So we have discussed different types of 3D printers different printers are working on different mechanisms and different technologies. Now where are these printers exactly used ok what are the applications of this kind of printer? So mainly these printers are used for prototyping and product development industries ok. For example, if we design something and we need to check whether it performs the same as what we have made what we have like formulated through theories we need to make that object in real world right.

Earlier, we used conventional processes like CNC or lathe milling, which require a lot of time. These processes might take from a week to a month to complete an object, and even after receiving the object, if it has any problems or requires design changes or modifications, a significant amount of time is wasted. This is not a viable option or mechanism for producing something. Now, we have 3D printing technology. With 3D printing, if you need to make three different kinds of things or sets of models, you can do it all at once. As I mentioned earlier, if we need three different varieties of the same object, we can place those objects on the same print bed and get all three versions at the same time. Once we finish designing the model, we can start printing it, and depending on the print size and print bed, which depends on the printer, we can get the output within hours or even within a day.

This is the major advantage in the prototyping industry. Additionally, 3D printers and 3D printed objects are so reliable that even for product development, people have started using them. Mainly, not in mass production, but in cases like space organizations, especially ISRO, where 3D printing technology is used to check if certain components work well. This technology has already been implemented. In medical applications, we use 3D printers to produce implants and prosthetics, which are customized to each individual. Conventional manufacturing processes find this customization very difficult. With 3D printing, you can manufacture something that exactly fits each individual, matching their colour tone, body size, and other specific requirements.

This is a significant advantage of 3D printing in the biomedical industry. Different kinds of prosthetic hands and legs can be 3D printed, or implants can be 3D printed and placed inside a human body. These implants are lightweight and match the required size for that individual. We have seen different kinds of dental aligners. Nowadays, doctors use 3D scanners to scan a patient's mouth with high precision and detail. Technicians can get a 3D image of the mouth and use those models to create dental aligners, that exactly match the individual's dimensions. This is an advantage of 3D printing in the dental industry. Additionally, doctors now 3D print organs using MRI scans to create a real model of one's organ. This model helps surgeons analyze the condition and plan surgeries more efficiently. Thus, 3D printing is widely used in surgeries today.

Next, let's take a brief look at some objects we printed in our lab, and used in various projects. Here, you can see a backpack and an electronic enclosure that will be attached to a rat for recording and simulation-related projects. This backpack is flexible, and the enclosure is rigid. We used two different kinds of materials to develop the product. The flexible backpack has holes so the rat can safely insert its leg, allowing us to hold the electronic casing firmly onto the rat's body.

In conventional manufacturing processes, this would be difficult, but with 3D printing technology, we can easily design and manufacture the backpack according to the rat's dimensions for the project. The electronic enclosure, which houses electronic modules and batteries, would be very difficult to find in a ready-made store. Injection moulding would cost lakhs, but with a 3D printer, we can print it to the exact dimensions required by the PCB and battery, making it lightweight so the rat can hold it easily. This is one project. Here, you can see another bond simulation project using a 3D-printed case for a rabbit. The PCBs are tightly packed in this case, designed to use only the necessary space while holding the PCBs and batteries in a confined space, saving space and making them lightweight.

Next, we will see some other objects that are not just casings but functional 3D-printed parts. This is a medical auto-injector. Auto-injectors are devices used for immediate drug delivery to a patient, such as insulin or epinephrine auto-injectors. This is an epinephrine auto-injector used for treating anaphylaxis, an emergency medical condition. This device has all the components inside it to deliver the drug immediately to a patient experiencing an anaphylactic reaction. One of its parts was shown in a previous lecture, and this is a headband with both flexible and rigid material.

So this headband consists of both materials, a flexible and rigid material, and it is used for easy acquisition. This has a rigid part here and here, and all others are flexible, so the user can wear it comfortably, and we can get a really good skin-to-electrode contact from this headband. This is another size-adjustable headband with only the rigid material. This is also used for easy acquisition, and this is an acquisition unit that, as we said, can be modelled accordingly, so it will have minimal interference or noise from the outside. That’s how this thing is designed and developed, and this is FDM printed, while all others are SLA 3D printed. As I mentioned, we can select the process we need based on the requirement; for example, if it only requires a casing and doesn’t need high accuracy, we can always go with FDM 3D printed parts. However, if it requires high detail and accuracy, it’s always better to choose SLA 3D printers or SLA printing technologies.

Now, what are the limitations and challenges that we are currently facing in the 3D printing industry? Of course, even with such a huge variety of materials, these materials are not enough to meet all our needs. Some materials cannot be used with low-end 3D printers, and if we need to use some kind of carbon fibre for FDM 3D printing, then we need to invest a lot in the machine. There are also certain materials that we badly need but are not available in the 3D printing industry. Material is a major limitation in the 3D printing industry, along with design complexity.

For example, if the size is very complex, we must have some kind of support structure. Once we remove that support structure, we will have support marks on the printed surface, requiring additional post-processing to make it a finished product. This is one of the negative aspects of 3D printing with supports. Some printers don’t require any support, but of course, those are more on the expensive side. Then there’s the issue of printing speed and size. Generally, all 3D printers are very small in size, at least the ones available in desktop sizes and for hobbyists. If we go to the industrial level, then it’s another story; we have very large 3D printers that can even print a part of a car in one go.

But on the other hand, almost all other 3D printers are very small in size. Even if there are 3D printers with a print size of 500 by 500 mm, if you print something large, there's a high chance that the part won't come out properly. So that's a major disadvantage in 3D printing; when you print larger parts, there's a chance they won't come out correctly.

Then there's criminal activity. You might be thinking about criminal activities that can be done with 3D printing. Recently, there have been many reports of people making firearms with 3D printers. If someone has a 3D printer and a gun model available, they can easily 3D print a gun model and use it for criminal activities. It's not that it's untraceable; with the technology that our government has, it's very easy to catch people who engage in such criminal activities. But please don't indulge in such activities; I'm just mentioning these challenges in 3D printing. We've even heard that the New York government has banned people from buying 3D printers, allowing purchases only if their criminal records are clear.

Then, the future of 3D printing. As we discussed, advancements in materials are the major future of 3D printing. Researchers are working on developing new materials for different kinds of 3D printing, as well as on bio-printing. In the future, you might be able to see a bio-printer that can print your heart or any of your organs, allowing you to transplant malfunctioning organs with a printed part. Research is even progressing on developing living tissues with a 3D printer. This is just a demonstration of bio-printing. Future advancements will also include integrating 3D printers with other technologies. For example, a casing could be 3D printed, and you could automate the casing to enclose or hold each electronic component inside, even allowing for the removal of a PCB, making the casing compact. That's one kind of integration with other technology, and there are numerous other technologies like automation, printing, and everything else.

Here you can see a 3D-printed house. Even in India, many teams are working on construction based on 3D printing. They use robots to deposit concrete in the same way as the FDM mechanism. This robotic head can move and deposit the concrete exactly as needed, and it can essentially print a house or something from scratch. This is a major advantage of 3D printing in construction areas. How will this affect us? How will it provide an advantage? That's a major question. Once we are using 3D printing to build a house, you can build it quickly. If it's a big project, you can even save money, and you can see how complex the shape can be. There are many limitations when manufacturing something using conventional methods, but when using 3D printers, the robot will take the job, and you can even make very complex shapes using 3D printing technologies. In the future, we might see different kinds of parametrically modelled houses. I hope we can see it soon.

So that's the end of this lecture. We will see you in our live lab session, where we will teach you how to use a real 3D printer and how to convert your ideas into real objects. That will be shown in the live lab session. I hope you all understand the lecture well. If you have any queries, feel free to contact us through our NPTEL portal. We will be happy to assist you and thank you, that's all.