Mathematical Aspects of Biomedical Electronic System Design

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Week – 12
Probability Distribution and Biomedical Systems Design

Lecture – 42

Aspects of Biomedical Electronic System Design

Hi, so this is one of the lectures in which we want to summarize what we had been teaching through TA classes on how we can put different concepts together and tie it up and see how it falls under the bigger umbrella of Mathematical Aspects of Biomedical Electronics System Design, isn't it?

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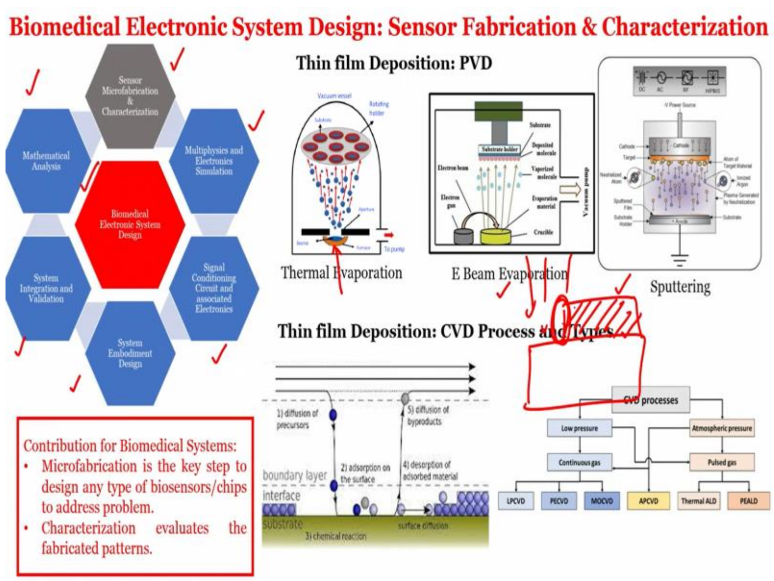

So, let us go through some of the slides today. We, you have been learning in this course, a lot of math, and at the side, you are also learning about several design and fabrication of sensors, and you are also learning about application of sensors and electronic systems. And then, we are merging how to use the math to help, to form the modeling. And that will help finally in simulation followed by fabrication followed by electronic system design and then application of this particular product. So, that makes the complete circle.

Circle can be this, not like this, but the point is how we are connecting each dot and how it will be useful. And what are the next steps that one can move or take after understanding this particular course so that was the idea. If you see this slide then this slide, you can see that when we talk about Biomedical Electronic System Design, which is right over here, in the center you, you are talking about sensor of fabrication, and characterization, you are talking about multi-physics and electronic stimulation simulations.

You are talking about signal conditioning circuits and necessarily electronics. You are also talking about packaging of that, that comes into the system and embedded design that is system integration and validation. Finally, there is a mathematical analysis that makes this entire Biomedical Electronic System Design. And that is, why understanding the concepts of math for this particular research, as well as this particular domain is very important.

So, in this, we have looked into several techniques I will just go through some of the slides in which you will just re understand or visit, revisit the topics that we have been discussing. So, the first one is the thermally operation system. We understood that by heating the metal or the material in the board, right, it gets melted and when it gets melted, it gets evaporated and that it, evaporates and deposits on the substrate, substrate can be silicone substrate can be glass substrate can be polymer, everything falls under vacuum since is also called vacuum deposition.

Then we have seen EBV operation. EBV operation is used when the material that you are using for evaporation has a higher melting point than the material of the board. Because if the material has a higher melting point, then that of the board you cannot melt it in thermal evaporation. So, in that case, we use crucible, and then we use the electron beam to focus on the material there are multiple ways of intending the beam like Point Source or scanning, or triangulation. But in any case, the point is that using the electron beam, we can melt the material and the material will deposit on the substrate.

The third one that we have seen under the vacuum deposition is this sputtering. Sputtering is a mechanical way of dislodging the items from the material and those would be deposited onto the surface that is using the Argon gas. And the substrate is at anode and this target is at cathode and when we apply a voltage, that is, DC sputtering, or if you a RF, then it is RF sputtering, there is a magnetron that can improve the rate of deposition, also uniformity of the deposition.

So, this all three things, thermally operation, electron beam operation and sputtering this falls under thin-film deposition or PVD, which is called Physical Vapor Deposition. Then we have seen another part of the thin-film deposition, which is called Chemical vapor deposition. And in Chemical vapor deposition, you have seen a, several different kinds of chemical vapor deposition.

Some of the things are discussed in this course. Some of the things are not, if it is not discussed in the course, please look into the several books that is already given in this as reference list. You can look in the Google, you can look at the previous courses in NPTL, which talks on sensor fabrication, which talks on our clinical perspectives, which talks on Opamps, and you will see that at some courses, I think from deposition courses that we will be talking about LPCVD, PECVD, MOCVD, APCVD, thermal ALD, and PEALD.

So, as you know, that CVD is for chemical vapor deposition when you say LP is low-pressure, P is plasma enhanced, then metal oxide, atomic process CVD. So different kinds of an atomic layer deposition thermal ALD. So, several ways or several techniques are that in CVD process to deposit or to grow the film. The advantage that we have seen in CVD compared to PVD was that it will cover the surface, or it will cover the step, better than the PVD technique, so step coverage is better, because here the chemicals are reacting at every step. For example, if this is the step.

Let me just draw it here if this is the step that you want to cover this one, and you deposit the material using PVD, what happens is it will get deposited, but this area will not be covered correctly. But if you go for CVD then because the gas is everywhere, it will react uniformly, and the step will be covered. So, that is the advantage of CVD or PVD of course, there are some limitations as well because in CVD process, the harmful gas needs to be properly addressed otherwise not really great to use the CVD techniques.

That is why it requires a proper clean room environment to use these kinds of techniques, particularly when it involves the exhaust gas, which are harmful for the body. So, contributions in terms of biomedical systems, microfabrication is a key step to design any types of biosensors chips to address the problem and characterization evaluates the fabricated patterns so the, this is one part of it. Where you understand that, how the metals are deposited.

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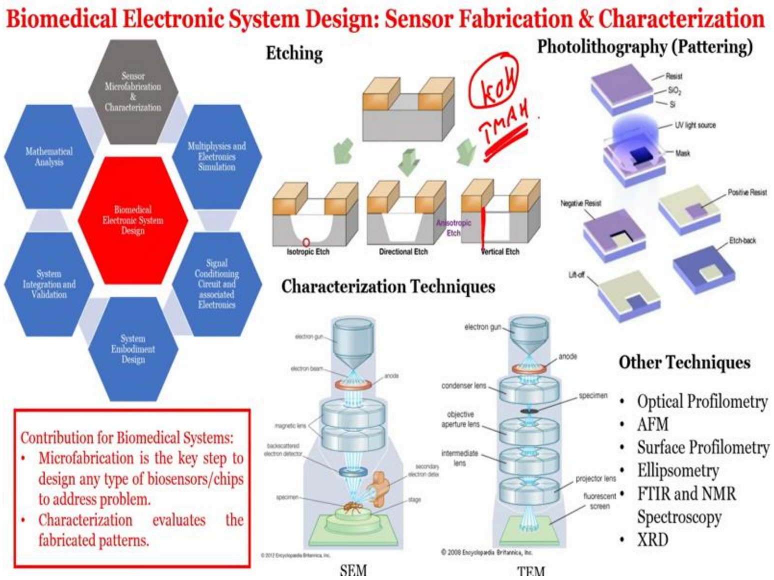

Now, once it is deposited, what you need to do, you are to also create a different pattern and how to kind of create, different patterns by using photolithography. That is why when you apply, when you say that Electronic System Design and Mathematical Aspects, what is within the electronic system design are sensors.

And that, is why we wanted to after discussing with professor Chandramani, who is leading the course, we wanted to see that how the sensor design and Lithography could help to understand the whole concept correctly. And that is why, if you see the slide, once again, the lithography, which is patterning has a photo lithography there is E Beam lithography and there is X ray Lithography and that there are characterization and techniques, which are like DRI or wet Etching.

So, Etching techniques like dry Etching and wet Etching, in dry Etching we use reactive energy or debater, in wet Etching we use different chemicals, for example, if it is silicone Etching, we use KOH and TMAH, that is potassium hydroxide, and the tri methyl ammonia hydroxide. And you know that this is done at room temperature at 25 degrees centigrade KOH is done at 80 degrees centigrade to increase the rate of etching, or etching rate compared to TMAH in KOH.

The walls that you see are rough in TMAH, the walls that is there, this wall, right, is smoother when use TMAH, TMAH is neurotoxic, KOH is not so, but everything should be used under the wet bench environment with the proper exhaust. So again, why we are using the Lithography or why we are learning Lithography, because we want to understand how the patterns are formed. Why we are learning a Etching, because the sensor is fabricated.

Now, we go for SEM and TEM. SEM, as you know, is the Scanning Electron Microscopy, TEM, transport Transmissible Electron Microscopy, there are other characters in techniques like AFM, which stands for Atomic Force Microscopy, there is Ellipsometry, FTIR, XRD X-Ray diffractogram. So surface profilometer and NMR. So, these techniques are used to characterize the material that we are deposited on a substrate.

Also some of the techniques like SEM would help us to understand the morphology of the material, morphology of the design light and SEM, can be an SEM and FESEM fuel emission SEM depending on the type of the structure that you want to visualize not visualized , you want to see, which is not able, we are not able to see in optical microscope, you go for the SEM.

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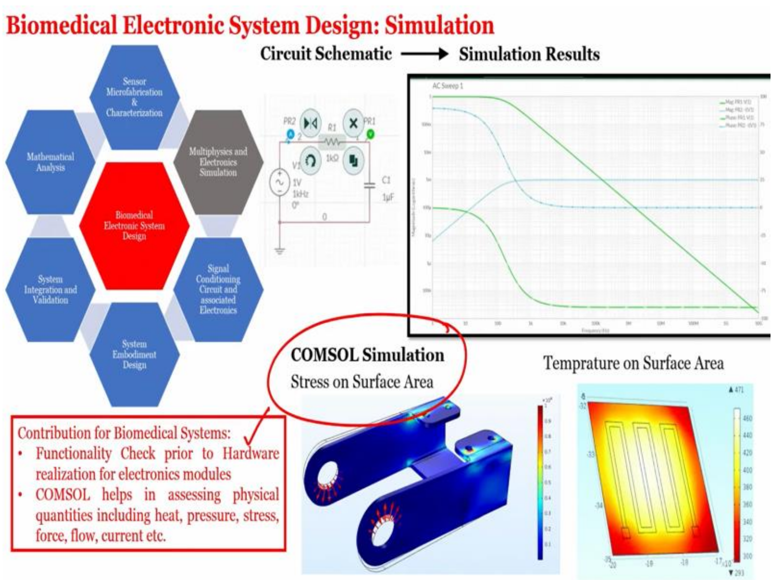

So, if you see back in another thing that we have discussed is the, a simulation, We have used COMSOL simulation, and then we have taught how this simulation will work. And we have also showed you the different way of modeling this particular material. Let us take an example of a heater. Then you can see that how the temperatures of the surface area can be measured by applying a given power.

And this COMSOL simulation is very helpful because know, before we actually fabricate the sensor, if you know the simulation result, then you can adjust your parameters accordingly. So, the functionalization check prior to hardware realization of electronic module is what the COMSOL simulation will help. Of course, there are other software also, but we have shown you one of the example of using COMSOL, COMSOL multiphysics. Also, it helps in accessing physical quantities, including heat pressure, stress, force flow, and current.

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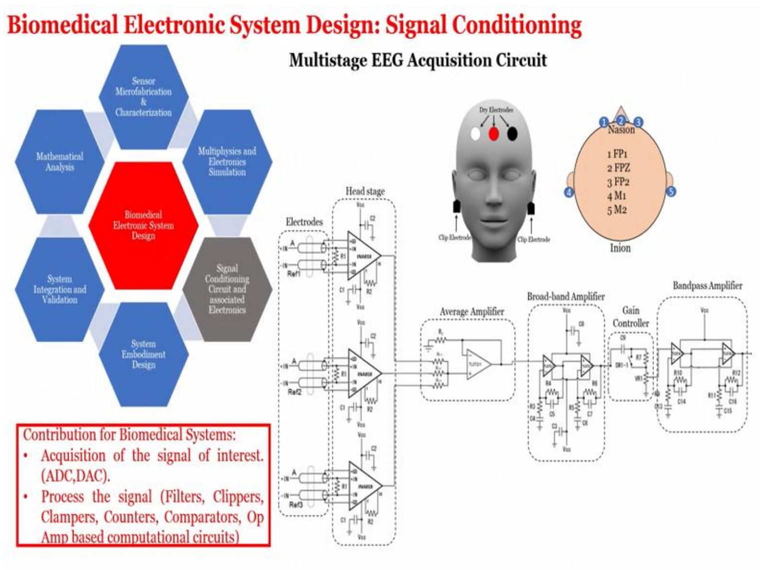

Then once you kind of understood how the sensors are fabricated and how this pattern, right, how do the characterization techniques are there, we move to the application of the entire electronic system. So, what is the application that we started with EEG, if you remember EEG, and if you can see on the slide that we were talking about the different regions.

The frontal region, frontal region is here, here, exactly here then there is an occipital region just exactly at the back, Where, and is used for visualization. Then there is a temporal region. There is central region. So, there are several regions in the, in the head that are divided into different parts so as to understand that, where to keep the electrodes.

Generally, you may have seen that 10-20 system is used for measuring this EEG signal, however now for a certain application. And of course, you have to have a reference in the ground that you already know for certain applications like neuro neonatal screening here, a hearing screening if you apply a given signal, which can be your ABR, you will be able to see the EEG signals from the frontal electrodes.

So, another the technique for measuring the EEG are different audio stimulation. One is ABR another one is AEP. Another one is mismatched negativity. Another one is positive P300 milliseconds. So, there are several different parameters that one can use for designing this audio stimulation. This is a very important problem because in our country, particularly not of neonates, does not go under the neonatal hearing screening because of the lack of the facilities in the primary health center.

And that is why if you can develop a band that can be placed on a neonatal head, and we can tell that whether can hear neonate can hear, or maybe hearing, or may not be hearing, and the parents can take the baby to the tertiary clinic, then the, this testing can be done accurately. The importance of this testing is that if the, if the parents would not know and the baby is already, the baby is 2, 3 years old, that will affect the cognitive ability because, the baby can not hear till 2, 3 years.

Whatever we understand and how we learn is by having our audio and visual and the speech all together working. Is not it? So, if I say some word, you are able to process it because you can hear it, but if you cannot hear it all, you will not be able to process it. So, overall cognitive ability may get affected, and that is why very important thing is to understand how to use this multi-stage EAZ acquisition circuit to develop this particular band.

So, we went into details about the electronic system, but when you are going talk about electronic system, we are also talking about electronic module. And when talk about electronic model, particularly EEG signals since EEG signal points in micro volts compared to millivolts, of ECG. If you measure ECG, it is about millivolts. If you measured EMG about millivolts ECG, electrocardiogram, and it is from the heart, EMGs from the muscle, the electro myocardial gram EEG is electroencephalogram that is the brain signals.

Now there is one more called ECOG that we may not have discussed in this particular topic, but ECOG stands for Electro Cortiography. That is a signal from the brain. This EEG is little bit different than ECOG because EEG is from the scalp electrodes from the scalp, there is an impedance that is provided by the skull. And that is why the EEG signals are different than little bit different than the ECOG the signals.

However, both originates from the brain. So, we understood how to place the electrodes or how to use the electrodes with the head stage and what, how to use the amplifier, whether it is a broadband amplifier, how to control the signals, how do we adjust the gain and how the band pass filter would work, is that it. So, acquisition of the signals using the ADC DAC processing signals using filters, clippers, clampers, counters competitors, Op amp based competitions circuits, all we have covered in this particular course.

And that actually is the core, so sensor is one part signal conditioning is one part simulation is one part, and application is one part, and whole thing is covered by the math. Because you require a strong math background to process all the other parts. Whether you do a theory and then you apply for modeling, then you apply for simulation a whole concept comes from your basic math. And that is why this course is of at most important to understand the remaining side of this electronics.

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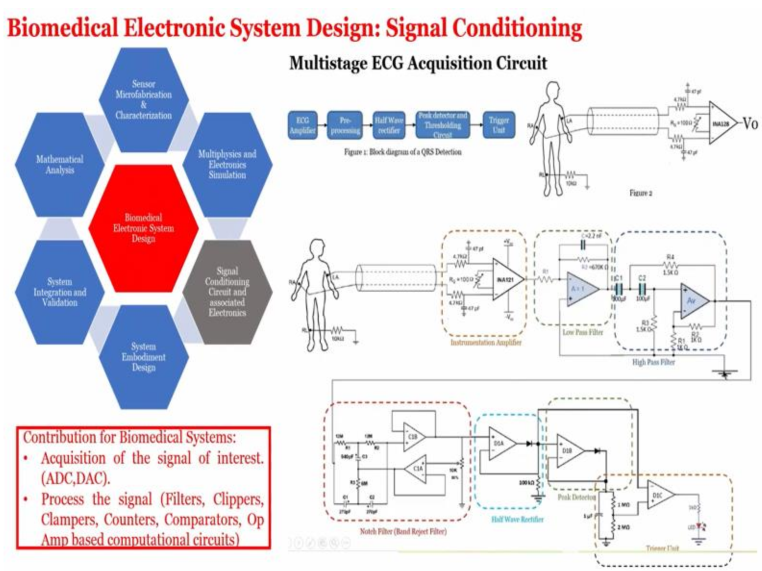

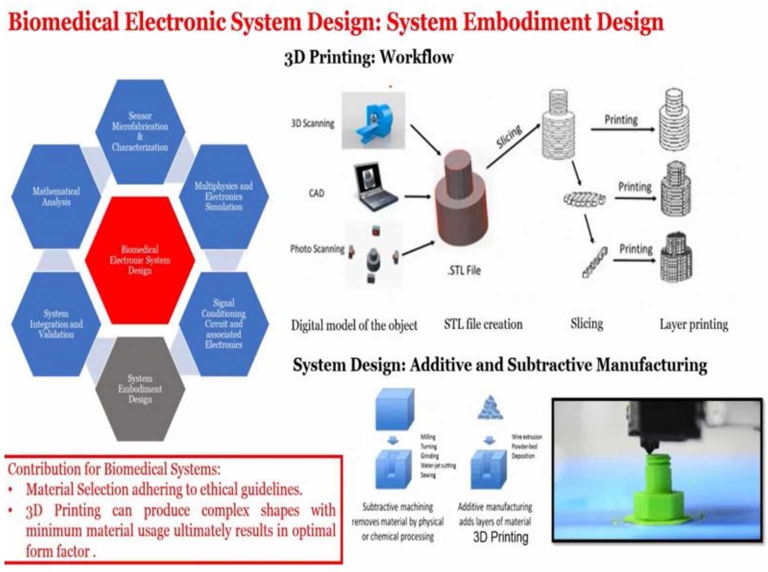

So, let us go to the next one you have also seen ECG, Multi-state ECG acquisition circuit in which we have shown how to design the complete electronic module, whether instrument amplifier was there, or high pass filter was the low-pass filter was there or it is a bandage filter or notch filter, half wave rectifier, trigger unit. We have also discussed the how do detect the QRS using this electronic module. And the other part that we have been discussing is on the 3D printing.

Now, see that now, when you say electronic system design, once you understand sensor, you understand electronic circuit. Once you can develop the entire module, you have to package it. Packaging there are many, many techniques to do packaging. One of the techniques is 3D printing, and we have been discussing in detail how the 3D printing will work. There are several different kinds of materials that one can use SLA PLA and what not.

But the point is the basic understanding about how to create the CAD file how to store it what is the requirement, this is what is covered and it is absolutely important, because there are two ways of doing it, of course there are others subtractive machining techniques. Here we are talking about adding one is a subtracting. So, subtractive manufacturing, additive manufacturing. So, we have discussed those details. We have also seen how to 3D print or how 3D printing can produce complex shapes with minimum material usage rate and ultimately results in optimal form factor.

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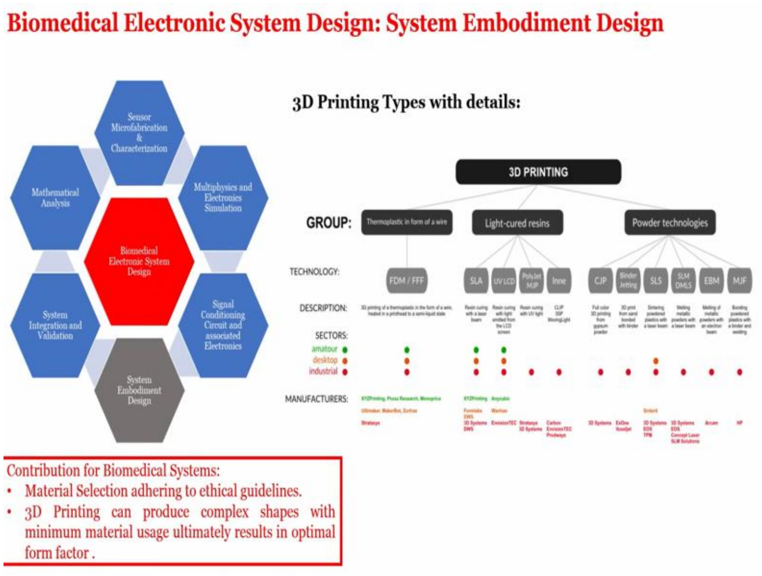

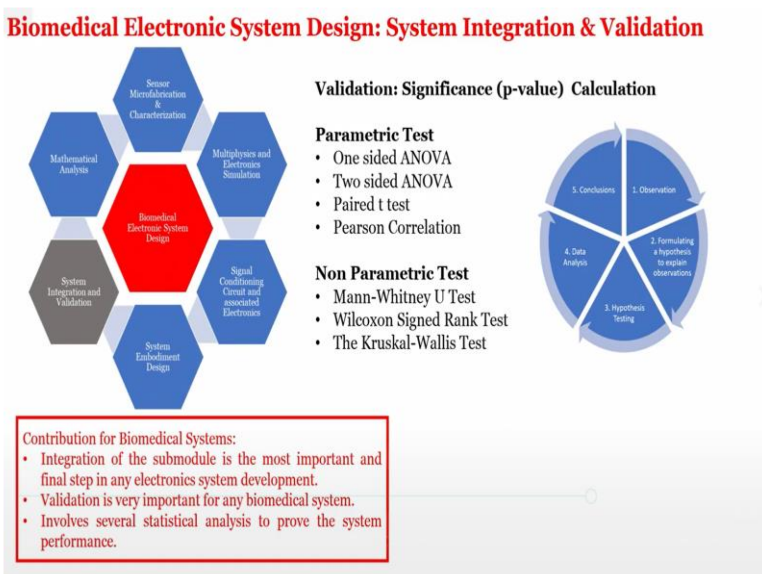

So, that is another part of the topic that we will be discussing, or we have discussed if you see the 3D printing further, and we talked about different technologies, whether it is a thermo-plastic in a form of wire or the light cured resins, or this powder technologies. And we further discussed FDM FFF, or we discuss the SLA ULCD PolyJet, Inne. We also did a CJP, binder jetting, SLS, and many more.

So, we have tried to cover as many topics as possible within this given period. Then we have also understood the integration of the sub-module, which is the very important part in the final step of any electronic system development and validation is also another part that once you make our system having validated the system. And finally, the statistical analysis that will help to, to prove the system performance, right or understand.

So, we have seen several statistical test parameteric tests, whether it is one side ANOVA, two sided ANOVA, Paired t test, Pearson correlation. We have also done the nonparametric test Mann Whitney U test, Wilcoxon signed rank test, the Kruskal Wallis test and so on and so forth. So, the point is when you start, you have to observe, then formulate a hypothesis, hypothesis testing, data analysis, and conclude with that. So, we have seen the entire cycle again, statistics involve a very heavy math so that is the idea.

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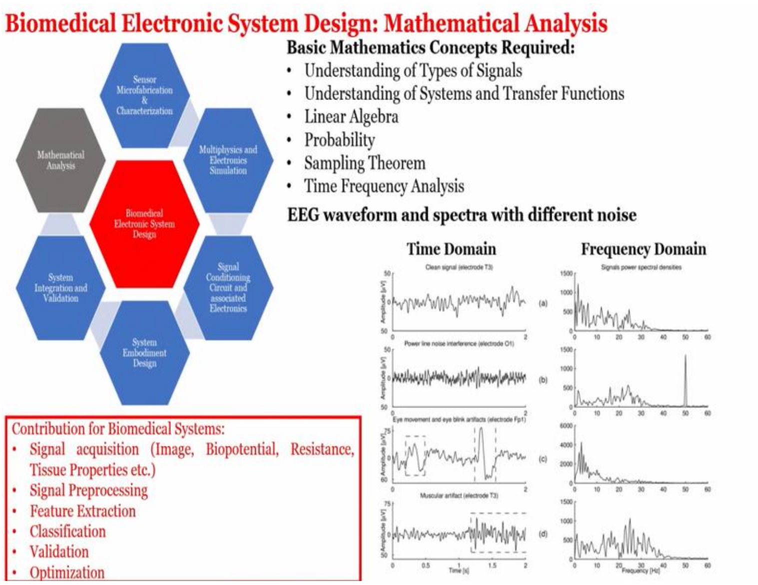

Then we also understood the basic math concept that are required to understand the time domain frequency, domain, EEG signal, how to process it. So, what you require for that? We required if understanding different types of signals, you understand different type of transfer functions, linear algebra, probability, sampling, theorem, time frequency analysis, all these are covered because this all will finally result in a biomedical system right from signal acquisition to pre-processing feature extraction, classification, validation, all the way to the optimization.

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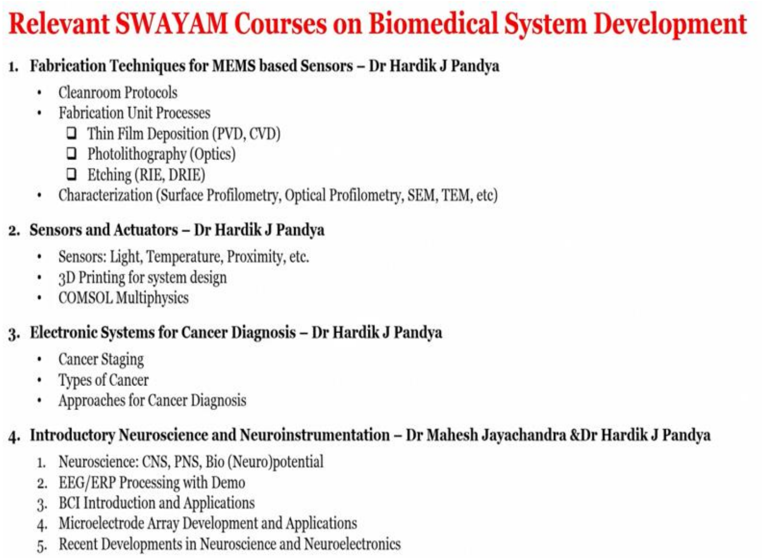

So, now you would, I am hoping that with this particular thing that we are discussing here, you were able to understand that how different dots can be connected together, and this can be seen that why you have to learn different topics under the under this course. And how it will be useful for connecting several things when we talk about electronic system. Electronic system does not only mean that you take a sensor, take a 3D printer and put sensor within the radiometer.

No, in electronic system design it is way more complex than it is it looks like. So, it has several factors into the game. The first one as I am re-iterating is the sensor design, when you design a sensor you have to then do the modeling of that. You have to do the simulation of that. You have to fabricate the device, you have to design the electronics modules for the same, you understand that the signals should be processed and not noise. What kind of electronic module you design for the same.

And then, entire circuit should be packaged. So, 3D printing and when you utilize it how the whole system will work. For example, if you want to look at the biomedical robotics, you can use the same sensors and use the optimization theory to understand what is the best path to reach to a particular stage. So, that is called path planning. So, this path planning requires a heavy math.

So, when you talk about biomedical robotics, or you talk about robots for different applications, how to move it, what are different kinds of maneuvering mechanisms? This all requires you to have the understanding of math, understanding of sensors and understanding of the electronic systems that having said that once you learn this thing, you can also look into several other courses that are available in NPTL.

Some of those are fabrication techniques for memes based sensors, in which you can further go in detail and see how the etching is done, RI DRI that is discuss in detail. There are several characterization techniques. If you look at sensor actuators, we have discussed the way more in detail about COMSOL Multiphysics, 3D printing system, electronic system for cancer diagnosis, we have shown different kinds of staging of cancer, types of cancer what are different electronic system that can design to diagnose this cancer.

And then recently Mahesh has taught a course on the introduction of neuroscience and neuro instrumentation. While I took few topics to help him out, which is a neuroscience, CNS, BNS, biopotential EEG, ERP, BCI, microelectrode array development, recent developments in neuroscience and electronics. So, several things you can further understand and go through which I believe will help you to, get much more familiar to the concept of electronic system design for biomedical applications.

So, with that I thank you I hope that you enjoyed this entire course and I wish you all the best for your exams. If there are any things that you always can approach the TAs, who are working with Chandramani Singh and of course our professor Chandramani Singh or using the NPTL forum. Till then I wish you all the best. And I hope to meet you in one new course sometime in few years. Until then take care. Bye for now.