Advanced Neural Science for Engineers

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Lecture 27

Role of Fabrication in Neural Engineering

Hello everyone, welcome to the course Advanced Neural Science for Engineers. I am Rathin Joshi TA of the course, I am also a PhD student as BEES Lab, Department of Electronics System Engineering, Indian Institute of Science. So, in today's TA class, we will be quickly looking at some of the basics of MEA based neural signal acquisition.

We will also see the role of fabrication, microfabrication in the field of current neural engineering research, and we will also see one example of how and which kind of neural probes are used to obtain this particular MEA, MEA is nothing but Micro Electrode Array. Generally, as a primary method, you use EEG and put electrodes on your head. Whereas, when you want to go deeper inside the brain, when you want to, after neurosurgery you want to have more precise.

When I say precise means, it is like your bio potential with higher resolution, higher spatial resolution. In those kinds of things, you need a microstructure to have a particular design patterned microstructure. So, that how will we do? With the use of micro fabrication. Already Professor has covered the several aspects of micro fabrication. So, will not go into the detail we will quickly glance through that. And then we will see the different techniques to record a different form of neuro potential.

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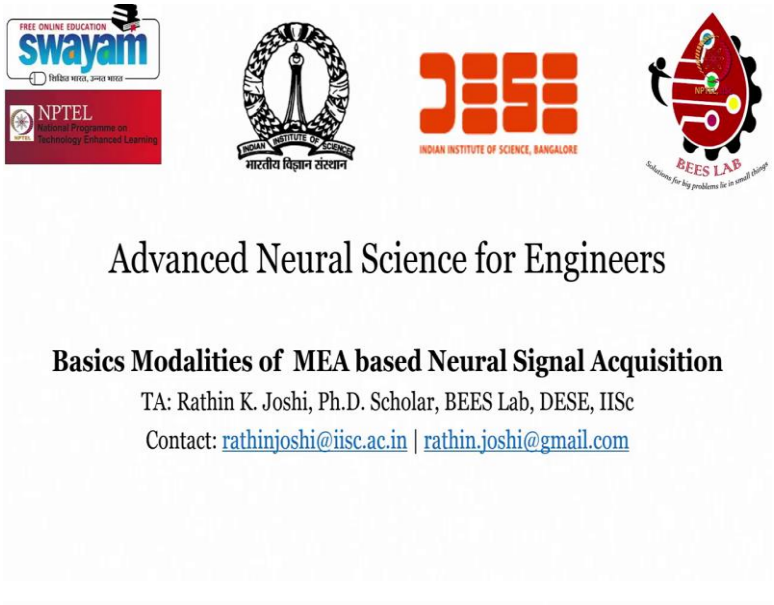

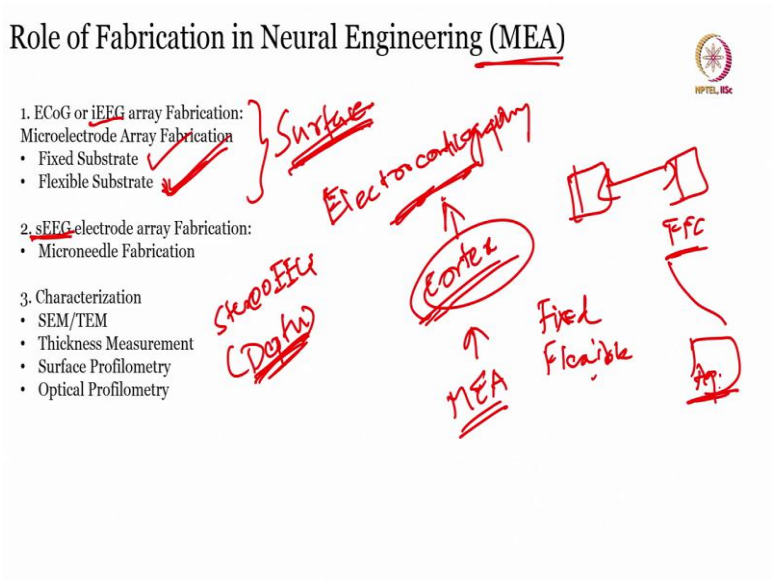

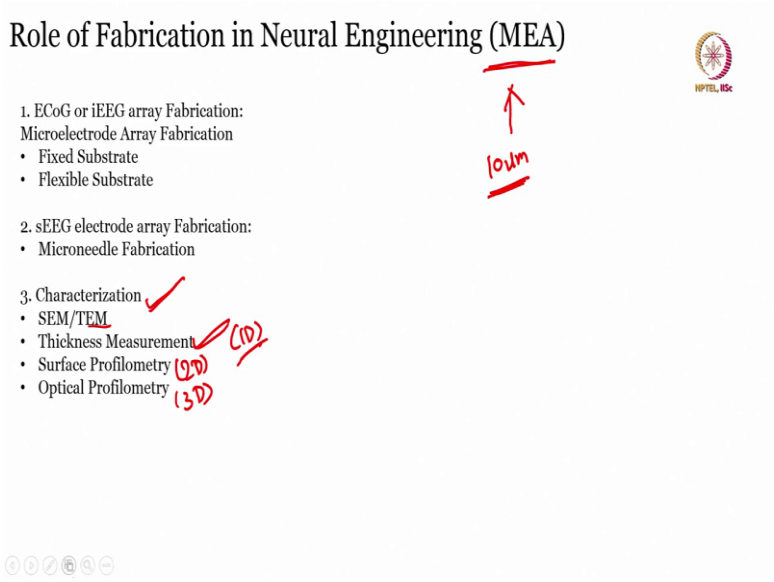

So, let us quickly see the type of, role of fabrication in micro electrode arrays. So, basically and primarily it is used to develop an ECoG array. Now, when I say ECoG, ECoG is an Electrocorticography. What it does is, this cortico stands for that recording from cortex. So, your brain has outer region of cortex, it records your data from your cortex and this can be done using as I mentioned MEA; Micro Electrode Array.

Now, micro electrode array is nothing but on a one proper substrate this very simplistic illustration, let us say this is substrate, you will have a different design. Now, this design this is just a side view, this, if you see from the top, it is going even to a different structure and all, ultimately it will go to the contact pad from there signal would be acquired. So, this substrate can be made up of a fixed substrate, it can be made up of flexible as well.

As you can see here fixed substrate and flexible substrate. Both of them is surface recording of the brain, surface recording. So, the thing is this ECoG or it is called iEEG, intracranial EEG. So, this has been done using two substrates one is fixed substrate and other one is flexible substrate. Sometimes when you want, this is like a recent development flexible substrate, it helps in reducing the tissue damage or the cortex and all.

So, that is why this is like more preferable when it comes to surface neuro potential recording. Whereas, the second type is sEEG, this is generally used during surgery as well, s stands for stereo EEG, where you go into the depth of the brain and record the neural potentials. So, this is like an overall view of, you already know how fabrication and process flow, micro electrode and everything would be covered in the part of course, but how it is actually used.

So, then from the surface where it gets generated, that is generated due to electrical network which is a result of millions of neurons. So, that generated neuro potential will be finally recorded from both the sides either from depth deeper region of the brain or from the surface region of brain that will further communicated to your acquisition box, but what would be there in between the sight of generation to your acquisition board.

So, this MEAs will have a contact paired, so that contact paired will have a connection with some connector known as FFC connector. And from there, you can connect it to your acquisition board. So, again, as I mentioned, this is just a rough idea of how entire experimentation happened. And how fabrication useful in terms of advanced neural science research.

So, now, we will see also one more aspect of microfabrication is used immensely in terms of advanced neural science research that is nothing but a characterization. Now, a characterization is as important as fabrication. What is characterization? Characterization is the method to validate your fabricated or micro engineered structure. This MEA, when I talk about MEA it is a few microns diameters, like few micron pitches.

So, characterization as I mentioned is as important as fabrication, why it is important because this micro electrode array, it is of a few micron diameter like let us say 10 micro diameter or let us say pitch, the distance between two consecutive electrodes, the electrodes can be rectangular in shape, can be square in shape, can be round in shape, this distance between two electrode is in terms of few microns, which we cannot see or validate from the bare eye.

So, what we should do is there should be some technique to identify whether the obtained microstructure is up to the mark or not. So, for that characterization plays a very important role. Now, characterization, there are plethora of techniques for characterization, it can be optical characterization, it can be mechanical characterization, it can be any other form of characterization.

Also, it is also classified as a contact-based characterization where your sample comes into contact of testing device or it can be non-contact as well; contact less. So, this SEM and TEM are the two imaging techniques, when I say about SEM, it records up to few microns when you want to record in few nanometers the TEM is used both are microscopic imaging technique. Also, when you get your structure done, you need to measure the thickness.

So, it is like a 1D measurement. You might need to measure your surface area, so that is 2D. And finally, your entire 3D structure. So, these are like just a different characterization techniques which you can use to obtain particular microstructure and also validate that particular microstructure. So, now we will see the next thing.

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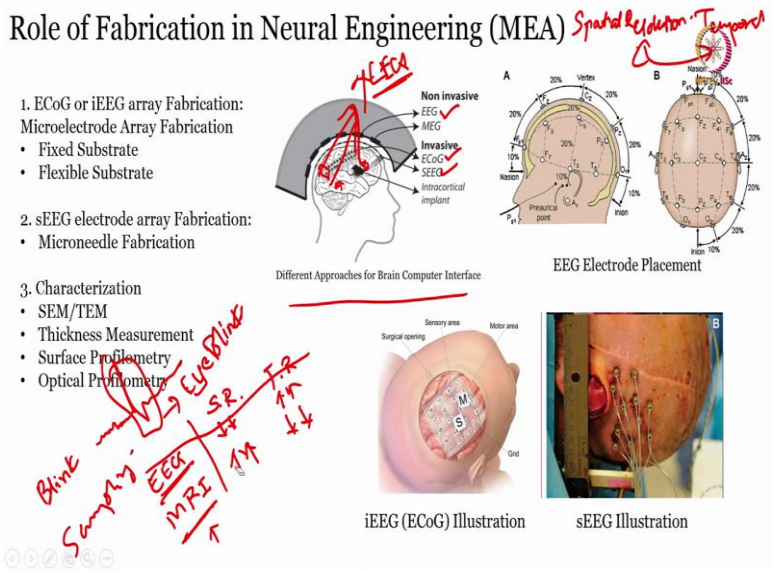

So, as I mentioned, these are the three different aspects EEG, ECoG and sEEG. MEG is slightly different principle, further improved and get, you can get MRI and all this thing. So, this is basically that particular thing, your EEG, ECoG and sEEG the three things what we have seen. When I talk about depth thing, it is sEEG. When I talk about surface thing, it is ECoG. So, this already covered.

These are different approaches for brain computer interface for which application we should go for which approach depends on your application depends on the level of the disease or information you want to get. So, for all this thing, I will see in detail that what form of biopotential is recorded in EEG, ECoG, sEEG? What are the frequency of those bio potentials? How is the SNR? How is the spatial and temporal? There is always a tradeoff.

In between, it is very important thing. One is spatial resolution. And other one is temporal resolution. So, there is a tradeoff between this. I will quickly tell you. Let us see this is spatial resolution, this is temporal resolution, if I talk about EEG, and let us compare it with MRI. So, EEG has very poor spatial resolution in terms of few centimeters or something, because on this surface, outermost surface, what EEG you are getting, it is a result of many sources lying beneath.

It can be a reflection of something here, it can be a reflection of something here, can be reflection of something here. Cumulative effect of all will go. And finally, you will get EEG. So, it is difficult to identify or localize a source when you record the thing from outer region. But it has an excellent temporal resolution. We will see in the part of this course also in the lab, one of the lab videos that when a person blinks, there is a characteristic waveform, it is

like this is if your baseline of EEG, what is baseline will cover, let us say it is a normal EEG going and something like this come. So, this is correspond to the eye blink.

As I mentioned, we will see in the lab class, how it correspond to that. But the point of seeing all this thing is whenever a person blink, immediately within milliseconds, you will get the temporal resolution. Again, when I say millisecond, it depends on the sampling rate of your acquisition system. If your sampling rate of acquisition system is much higher, you will get a very, very quick response or very, very quick refraction of the, as soon as a person blink you will be able to see all this kind of blink pattern there.

So, EEG, coming back to here, EEG has excellent temporal resolution, but very low spatial resolution, but when you want to look at a tumor, or when you want to see a particular illusion inside the brain or something, and if your organ at that time, you need a very precise spatial resolution. At that time, MRI wins the, MRI is much better than EEG. And but it has a poor temporal resolution.

So, as I mentioned, it is about trade off that which technique you are using, what do you want to use. Again, in terms of we will do the comparative analysis in between EEG, ECoG and sEEG as well, where which thing is being used and how it is different from each other. But, compared to here, I just wanted to tell you about this spatial resolution, temporal resolution and all this thing.

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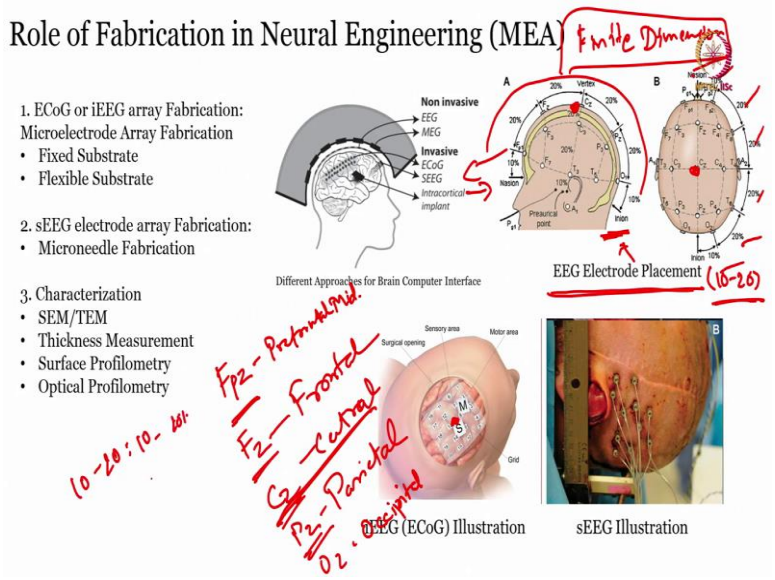

So, further, that is one more very important point is to know how this particular EEG electrodes would be placed. Now, this nomenclature follow across the modalities like

basically my head size is different your head size is different. So, when can we say that you cannot give a finite dimension to tell that which particular place of the head you are talking about. So, how to deal with that particular thing?

For that there is an electrode placement technique known as 10-20. Again, why it is called 10-20? Very quickly, this part whatever you can see here, it is known as nasion, it just above your nose. And when you try to touch and scroll your finger in the backside of your head, there will be a slight transition or trench that is nothing but your inion. So, just consider this particular thing nasion to inion consider this entire curvature what you can see here into 100 percent.

And then further you have to divide into like 10-20 bar? How 10-20 means? The first is this 10, again 20, 20, 20, 20 and 10. So, this 10 four times 20 it is nothing but 80 and again 10 which makes 100 percent. So, from your entire region from nasion to inion, everything you divide into 10-20 part and same thing you do from this side also. This is from the side. This is a side view of human face. This is a top view of human face.

So, again you do the same thing from nasion to inion here also. And again, in the same 10, 20, 20, 20, 20, 20. Now, accordingly the naming convention is provided. Let us first start with the side thing. So, after nasion at 10 point, whatever comes here if you can read it or not, that is known as Fpz. Further if you go 20 percentage up it is Fz. Again, you go at 20 percent up it is Cz. Again, you go 20 percent up it is Pz. And finally, it is Oz.

Now, why z? So, this thing if you can see here, all this midline electrodes or midline positions are provided, shown with z. So, this Fpz means it is pre-frontal midline. I will just write mid. When we go a little bit ahead, it is called frontal. Further, if you go ahead, it is the central. Then again it is something called parietal. This all are known names for the lobes. This is occipital.

So, this thing, if I talk, if you see this image if it is exactly at center, this can be your central lobe which is nothing but this here and this here. So, by different views and by dividing your entire head into this 10-20 partitions like 10 percent 20, 20, 20, 20 and 10, you can cover your entire head and main thing is independent of the dimension. So, it is like a worldwide used technique. Again, as I mentioned why it is 10-20, 10 followed by 20, 20, 20, same thing. Now, here, I will just clear this thing I want to discuss one particular aspect.

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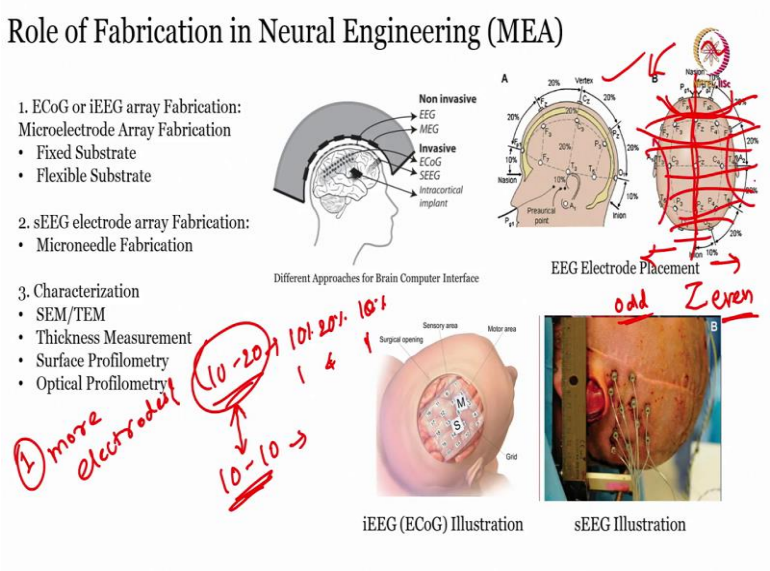

Here, we have seen 10-20 system. So, which has 10, then 4 times 20 and again 10, 10 percentage, once four time 20, and here one again 10. What if I go for 10-10 system? How it is compared to 10-20 system, what are the changes? So, this is like, if you have understood this 10-20 system, this and this properly, this is very easy to answer. I am just writing few questions based on this which I believe you should be able to answer if you understood everything properly and which can help you in your assignments or even in your final exam as well.

So, this is 10-20 system as I mentioned 10, 20, 20, 20, 20, 10. When it comes to 10-10, my first question is, which of this will have more electrode? So, again, it is a very, very, very basic question. And very, very easy question. Here you see, electrodes and everything is being shown. One another important point, if you see here, I told you about midline is preceded by z. But when I consider all electrodes this side, this is the top view all electrodes on the left side, all of them have odd number, see, Fp, because it is an prefrontal lobe Fp, but is in left side, so it is Fp1, F3, because it is a left side, it is in frontal space F3, C3, P3, O1.

So, all this electrode on the midline, this would be preceded by z, all this type of electrode will have odd numbers, all this type of electrode, this side of electrode will have even number. Also, along with that, all the lobes, this is frontal, this is central, this is parietal and this is occipital. Again, this side lobes are known as temporal lobe. So, it is a slightly clumsy here, but the idea of explaining all this thing to you is let you people know that what is one particular thing.

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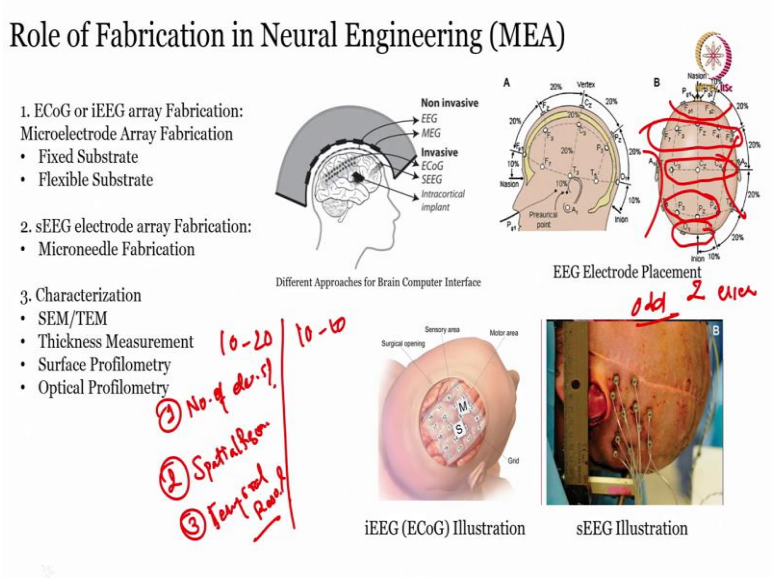

So, again, this is midline, left side electrode, right side electrode, prefrontal, this is your frontal lobe, this is central, parietal, occipital, temporal. It is a little bit cleaner than previous one. And again, z even number odd number, very easy. The first question was compared to this is 10-20, this is 10-10, first question was number of electrodes, I just write electrodes. Which one has more number of electrodes? Second question, a more important question, spatial resolution, which one of them will have a higher spatial resolution?

Third question, will the temporal resolution changes or not? Or which one will have higher or lower? First thing is whether it is different or not, if different, which one is higher or lower? So, these are the very, very basic questions like completely based on your understanding, if you have understood properly from the lecture or not, based on that you can answer this particular question. So, I will not answer this question now. I will leave it up to you. And let us see if you have any doubt regarding this, feel free to ask us on forum.

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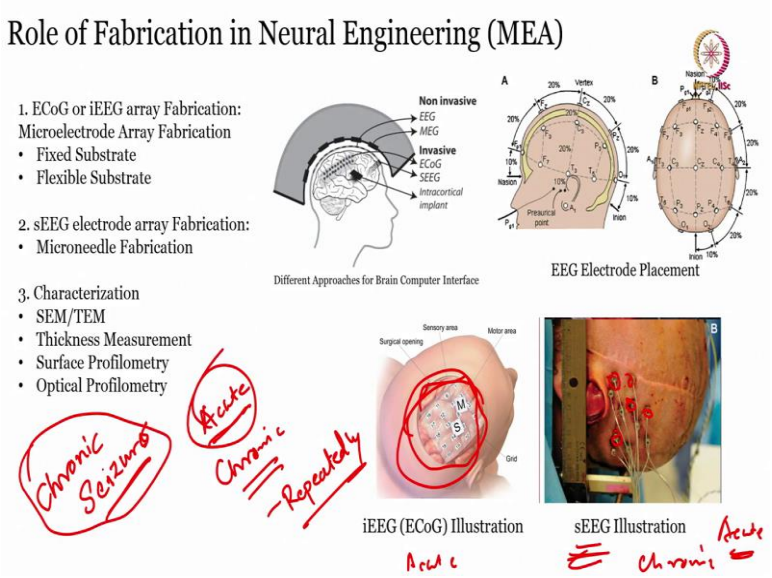

So, again, this is like a surgical opening and all. Here, one more thing, what I would like you to show is, see the expose region or open region is this much. Whereas, in sEEG, is just this much. So again, stereo EEG when your electrode is penetrated or in the depth, deeper brain regions, you can move it little bit here and there by the things. That is why it is called stereo EEG. And it is just a little bit area is exposed.

Whereas, if I talk about this particular aspect of cortical response, a large area is exposed. But generally, this thing is for acute excrement, this thing might be for acute as well as chronic also. Now, what is acute and what a chronic? It is like generally many diseases also have this name like if you have some issue with your throat or something audio pharynx it is called acute pharyngitis.

Now, why it is acute and why it is particularly chronic? So, chronic is generally in very simplistic term or thing or situation which occurs repeatedly at regular or irregular intervals. Sometimes you have heard the term in terms of epilepsy that person has chronic seizure. Now, seizures, seizure prediction is altogether different ballgame altogether when a person has epileptic when the next episode come, we might predict nobody can tell perfectly predict that particular thing, but it is chronic.

Chronic means we know it might come again it might not but it comes at some point of time, that is why it is chronic. Whereas, acute means it will be there for some limited period of time and then it will go away like in a very simplistic term I have told you can try to search in detail by your own.

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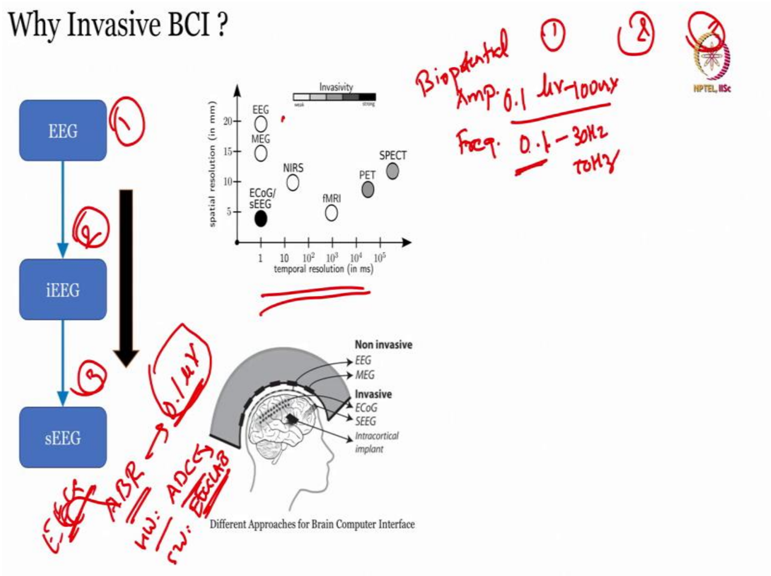

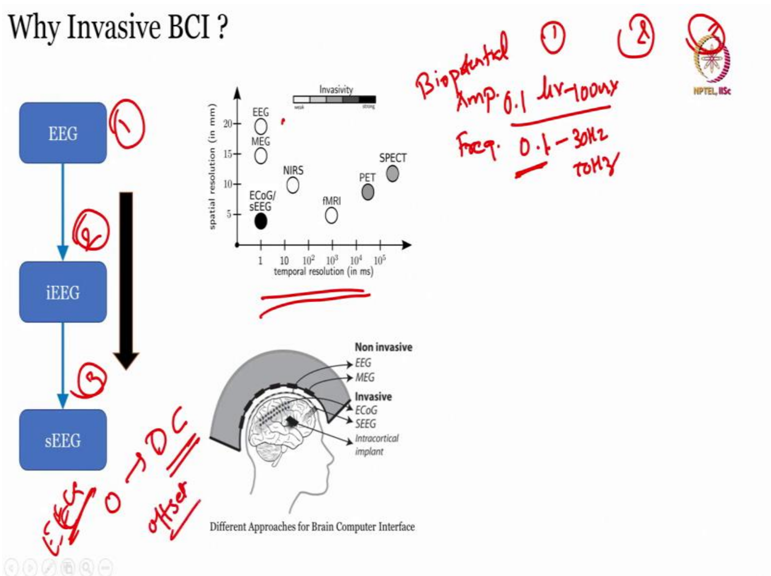

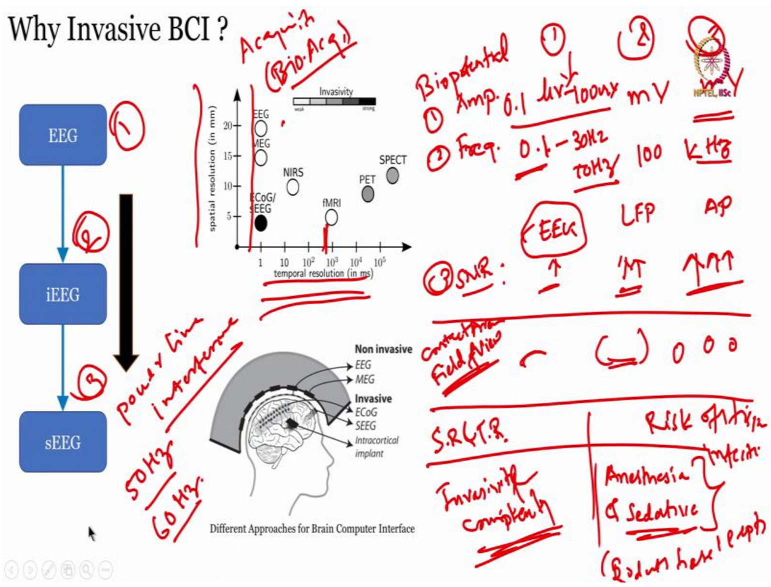

So, further if we move ahead. If you see this image, something has been open in the human head and all. Why should we do that? If you can record EEG from the scalp, why should we go into this much detail? So, there are own benefits of this particular thing by going from EEG to intracranial to sEEG. And it will give us more information so that compensates for the, like invisibility or complexity we failed during that.

So, we will see one by one, each of them. First one, let us say EEG, iEEG, sEEG. Now, all of you know the basics of thing what is iEEG, sEEG and all this thing. This is very, very important illustration. Now, this is EEG. This is ECoG and sEEG. Also, one more degree or one more parameter which has been covered in this particular research paper is invasivity. EEG you can see a complete white, there is no blackish or grayish thing here.

Whereas, when I talk about eEEG, it is completely invasive, but how it helps? You see here spatial resolution here it is in 20 millimeter, which is like around 2 centimeter. So, you can get some idea for the surface beneath your head or inside your head, but approximation would be around few centimeters. Whereas, if you go inside, you can actually locate something you can actually locate tumor and all within 5, particular 5 millimeter.

How this will help? Let us say you have a tumor in your brain you are trying to remove it, if at all, if at all some of your nearby place or nearby cortex or anything got cut, it might hurt eventually, because your entire network, see, brain and heart are two of the most complex organs and still research is going on not completely explored.

So, what happens is you might end up with cutting that particular area, which corresponds to your moment, you might have lifelong impairment, there are several neurosurgeries or procedures wherever person, there is always a risk associated with that. So, that is why it is highly and very, very important that you spatially localize the lesion or in simpler word, the bad area of the brain tumor of the brain, which you can remove.

So, this is like, overall idea. Again, there are other techniques NIRS and fMRI and PET and all this thing is all our imaging techniques will not go into the detail, but you can explore it by yourself. What I was saying is from this, let us say this EEG is 1, intracranial EEG is 2 and sEEG is 3. So, what I wanted to say is let us compare this thing that how and what things will change and it will give us an idea that why we should go for this and that.

So, first parameter let I will consider bio potential this all thing nothing but records bio potential if I talk about principle, bio potential and let us put some parameter of that, first is

amplitude, then let us say frequency and let us consider that this is 1, 1 is easy all of you know, 2, 2 is iEEG, 3rd, 3rd is my sEEG stereo EEG. So, when I talk about bio potential in EEG, there will be few micro volts.

Again, and I say a few micro volts, it can even go below that. There are some response known as ABR, auditory brainstem response. In one of the lecture of hearing screening professor would have covered it or we will cover now. So, this ABR thing is nothing but it gives response of 0.1 micro volt. So, you can have an idea how robust electronics would be required to faithfully reproduce this particular signal.

Again, there is a combination of hardware and software, first thing is very accurate ADC to get the analog 0.1 micro volt convert into digital signal transmit into your system. Once you get it into a system, this is hardware. Once you get it in your system, you should have compatible software to extract that particular thing. So, there is something called EEG lab. It is a facility available with MATLAB you can use this particular thing to extract the response.

So, this all things, this ABR is part of EEG only, this is recorded from your scalp non-invasively. So, this is like 0.1 micro volt. So, actually if you see everywhere they say EEG comes from 0.1 micro volt to 100 micro volts or something, but it can possible that EEG can be recorded from 0.1 micro volt as well. Again, when I talk about frequencies, it is again a different question.

But the thing is, you can go till most of the primary diagnostic EEG has a frequency point 0.1 to let us say 30 hertz or even 50 hertz some time, all this thing. Again, when I put here 0.1, there is a reason for putting 0.1 here, so why am putting 0.1 there is, 0.1, I am not writing here 0 because 0 frequency corresponds to DC. So, I want to remove that DC offset. So, that is why we are putting here 0.1.

In most of the EEG or ERP based amplifiers or bandpass filter whatever is being used, you will see either is 0.1 or 1 or 3 to 30 or something like that. Also, when I say 50 hertz, I need to take care of power line interference. Again, we will come to all this in detail in experimentation class, but why power line because we are in India. So, what is your electrical power line frequency? 50 hertz. If you go to US it would be 60 hertz.

So, accordingly band reject filter or notch filter should be used to get the faithful signal but this is all related to EEG. When you go little bit ahead in iEEG you will get millivolt signal, you will get little more a higher frequency let us say 100 hertz or more you can check the,

again, there are several ECoGs and whether it is stimulus evoked ECoG or normally ECoG and all you can check in detail this is also a millivolt and around you can get even higher response there in terms of this is like EEG it records all your sensory potential and all, this records your LFP local field potential, this records your action potential in terms of neural aspect.

So, this is like an overall idea this can go up to few hertz. Again, when you want higher hertz kilo hertz or something you need a higher sampling rate acquisition. So, that also your electronics will increase and your computational power also will increase. So, now for bio potential we have characterized in terms of one amplitude, second frequency and finally, the most important parameter is your SNR signal to noise ratio.

So, in EEG let us say it is this low, it is a kind of low whereas in iEEG it is slightly more, sEEG it is very more like there is a reason behind that, because here you are going, you are recording from the outer surface, here you are recording from little bit on the cortex, where here you are going to deeper region of the brain. So, this is like an overview of how things will change when you go from EEG to intracranial to a depth of the brain.

So, just an overall idea. Again, there are other things like how much contact area is also one of the parameter. And along with contact area there comes like field of view. If you ask neurosurgeon, they will tell you how the view actual view is, but, these two things. In EEG you are only recording from your scalp and when it comes to this thing you are showing up your head and then you are going into the cranial and all so you will get a bigger view which means the contact area is bigger.

Here, you have seen as the previous slide, there are very small cavities in which you will insert the electrodes and check the thing. EEG is anywhere accorded from human scalp. So, there is no issue with that. So, this is like again a comparatively connected point. Again, another thing is spatial resolution and temporal resolution both are always connected and you need to find out.

Now, if you see here this all thing lies in the same temporal resolution, whereas if I talked about MRI and all it has a poorer temporal resolution. So, these all three things will give you an almost equal temporal resolution as I mentioned again depends on your acquisition system. When I say acquisition system, it is like your bio potential acquisition system. So, all this thing, it is like same temporal resolution, but spatial resolution differs.

So, that is another thing. So, I will just write SR and TR that is already discussed. Along with that, we will see invasivity and complexity. So, here what we will see is EEG can be recorded by semi-skilled person. I work on noninvasive EEG also, noninvasive is best neuro engineering project I also worked with invasive experiments. So, even a semi-skilled person can operate EEG system.

You have a proper headband, you put it on your head, start the recording, EEG can be recorded. Like no skilled professional requires. When I talk about your iEEG it starts with for shaving of the head, then performance craniotomy, then put the electrode on the surface. So, that requires skilled professionals which means complexity increases.

When you talk about stereo EEG it is even more difficult, generally used during surgeries it can be used sometimes extra operative also outside of surgery to locate the seizures and all but you need a skilled professional to perform this particular experiment, you need a professional to put the implant the electrode array MEA what we have developed the skill profession is required for that. Also, you required a proper person to interpret the signal.

So, as you go deeper region in the brain, your invasivity or complexity increases. One last point, which I have in this particular aspect is effect of anesthesia and sedatives. So, this is mostly true for research and that are rodents-based experiment, rodents is nothing but your rats and all animals, rodents based experiment. So, in this kind of experiment, you will see that anesthesia is administrated just to take recording and rat would be in sedation.

So, there is the effect of each and every anesthesia dosage to a particular animal. So, all this thing. Also, there are some other aspects of risk of tissue damage and infection. This both things I am writing I have written on this side, because mostly it is related to iEEG and sEEG. So, this is like an overall idea, it has some disadvantage. Like every each everything in the life, it has some advantages and disadvantage, but you need to identify based on your application.

As I mentioned, if some person is epileptic and you need to remove particular thing, then you might have to go for a proper procedure and you might have to go for invasive where a person has a normal issue with their sleeping cycle or initially you want to do normal test, generally PSG is used polysomnography along with EEG, ECG and all other like oxygen levels around 16 parameters are used, we will not go into the detail.

But, for some primary application where you have no idea that exactly what is happening for primary diagnostic tool EEG is excellent, but if you have some serious issue, and then procedure needs to be carried out, and at that time, you have to go for iEEG and sEEG. So, these are like some of the brief overview of the technique used, where this is being used.

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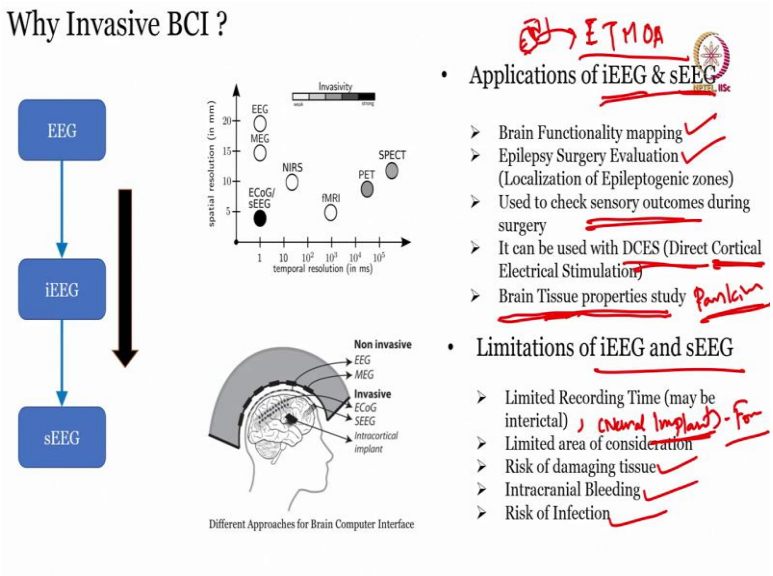

So, let us quickly one by one see this particular thing. Brain functionality mapping, it consists, it includes your sensory systems of your auditory system, visual system, etcetera. Epileptic surgery evaluation, post surgery, if you are getting seizures or not, whether you can localize it or not, this can be extra operative also, used to check sensory outcomes during surgery also, this also again a very important point when you are removing one particular area of your brain.

And then during surgery, you want to know whether, during surgery obviously a person would be under the effect of anesthesia or a subject would be anesthetic. So, what happens is you can check during surgery intraoperatively that whether a person's entire sensory system works fine or not, this is again one more aspects of that. DCES or DBS this is like direct, these are two kinds of electrical stimulation, one is direct cortical electrical stimulation, deep brain stimulation, these are used for Parkinson and recently in epilepsy and all this thing.

Parkinson is a movement disorder where person can hardly. I believe one of our other TA would have covered the detail aspect of Parkinson's I will not go into the detail. One more other important point is brain tissue properties. Now, when I talked about brain tissue properties, in your brain, let us say you have some lesion or some tumor, so, there are

different type of regions in the brain, let us say this is your normal region, this is your cancerous region.

So, you can, when you are doing the surgery, when you are removing this and you are checking this thing also this thing would be useful. It is a byproduct of doing this particular thing. Now, when I talk about tissue properties, there are different kinds of tissue properties which can be used electrical, thermal, mechanical, optical, acoustic, etcetera. So, there are different techniques of assessing a tissue based on that a person will decide whether that particular part of the brain is having lesions are not, is having a problem or not a very simplistic manner.

And also, there are some limitations of invasive EEG techniques. These are like recording time would be limited, you cannot completely open your cortex for a longer duration of time. If you want to do you can use implants, neural implants. So, it is again completely outside MEA would be there inside your head and you are covering it up. It is also like a foreign body, but you have to check the biocompatibility of the implant what you are using and all this thing.

Again, you can check at one particular procedure a limited area, risk of tissue damage, intracranial bleeding, infection, all these things I have already covered. So, these are like a gist of techniques what we are doing, why we understood iEEG, sEEG and all this thing. It also shows the importance of micro electrode, usage of micro electrode arrays, these are all things by the way iEEG, sEEG or normal EEG, iEEG and sEEG uses micro electrode, normally EEG uses macro electrodes.

Which type of electrode, if I want to record something from my forehead, and if I want to record something from my head, will the same type of electrode used whether that electrode would be a dry electrode or wet electrode, all these things we will see in one another TA class, but iEEG and sEEG specifically uses MEA. And for MEA, whether it will be used like flexible surface or fixed substrate all this thing will be covered in the next class.

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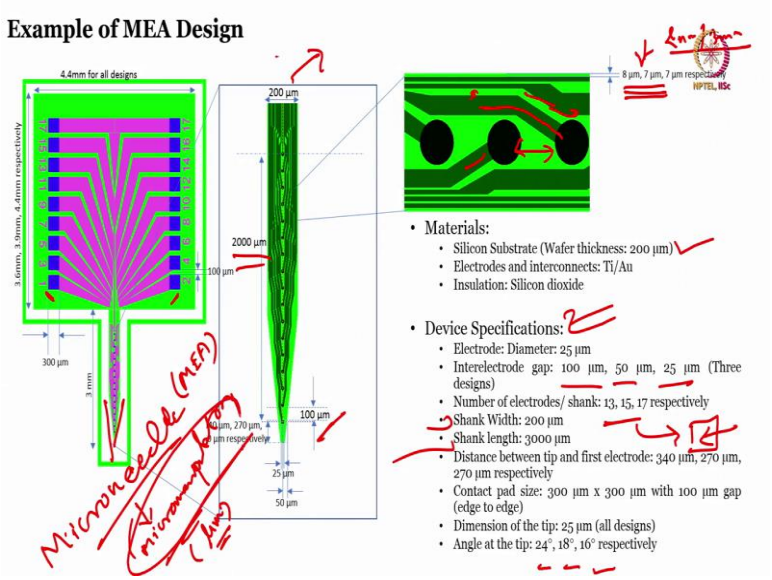

This is one more example, which I just wanted to have you, I told you right that from MEA, MEA it will go to the contact width. So, how it would be? So, this is like an overall design. You can see is hardly 4 centimeter width and around 4 centimeter or 3.6 centimeter based on the design, there are three different versions I will come to that. But you see this blue color part all this thing you can see here on the side, this is your contact point this will further connect it to your acquisition board.

Whereas your actual area is this shank, which is zoomed here. So, here if you see the entire area or MEA this width size is having just 200 micrometers. So, this micrometers patterning will happen using fabrication. And that is why we have given a proper emphasis on fabrication and fabrication techniques, this is just one of the design. Also, you will get an idea.

Again, if I go into the detail each and everything requires a separate TA class or separate lecture because what should be the difference between this electrode and this electrode. So, that it faithfully records the different signal or it can take care of spatial resolution. What is the difference between this line who is taking this recording and this line or this particular line who is taking from some other electrode? So, the distance also matters.

So, all these things again you see it is 8 to 7 micrometer. Also, how much thinner this can go. I told you right this is few micrometer. Now, fabrication successfully people have fabricated up to 2 nanometer or 3 nanometer. And even foundries have said that they can even go sub nanometer. So, then why should we stop at micrometers.

So, there is again another parameter that how this wire will conduct some form of potential some form of current and current charge density all this parameter will come into the picture. So, each and every parameter which you can see here or dementia, there is a lot of research a lot of reasoning brainstorming has gone around that and then we have finalized this particular dimensions. Now, we have used silicon.

Then again for electrodes which material to be used, whether it is titanium gold or should we go for some other but metal which can faithfully. If I talk about physically, this is just one metal which is conducting a potential from one place to another place and that potential is from our body. So, it will give us some idea. But overall the thing is, it records from this thing and it requires entire skin body, electrode interface and all this thing.

So, these are some device specifications for overall idea that what is the electrode diameter, what is intra electrode gap. So, here I have mentioned that there are three dimensions of the height corresponds to these three interelectrode gaps. Number of electrode, how much you are using.

Again, when you say number of electrode, you need to check that your further because this electrode will be connected to acquisition board. So, how many channels are available in that ADC. You have to take care about all this thing, check the impedance, check the flow and then you can identify design a particular system. So, again this angle, this angle also matters. So, it is also in three values. So, this based on different kinds of fabrication or patterning, you can get a desirable arrange.

So, this is like an overall idea this is one shank, this is called shank by the way. You see here shank width, shank length and all this is called shank. You can have a multi shank electrode also based on your requirement. Also, you can have something called micro needle, it is a form of MEA only micro needle it penetrates into the brain. And you sometimes required micromanipulator because when you are penetrating this kind of array, it is also MEA only micro needle, we have a needle of injection, something like that.

There is a needle, it penetrates into your brain and there is a micro manipulator which uses to precisely enter that particular device into your brain with few micrometer resolution, that is why it is called microneedle and micromanipulator. So, this device is also useful just to give you an idea. So, these are like overall idea to create a microstructure and get the neural implants or neural recording done.

So, this is the like, just the gist of different techniques whatever we have used. And I will see you in the next class in this particular discussion if you have any question at any time, feel free to write us into the forum and try to explore on your own this different EEG recording techniques and how different kinds of MEAs are used, which materials have been used, what are the dimensions and all, it will significantly help.

And it is like a current state of the art neural engineering research area, which I would like you people to come across. So, this is a brief of it. We will see you in the next class. Bye. Take care.