Computational Electromagnetics
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Applications of Computational Electromagnetics
Lecture – 14.01
Inverse Problems - Introduction

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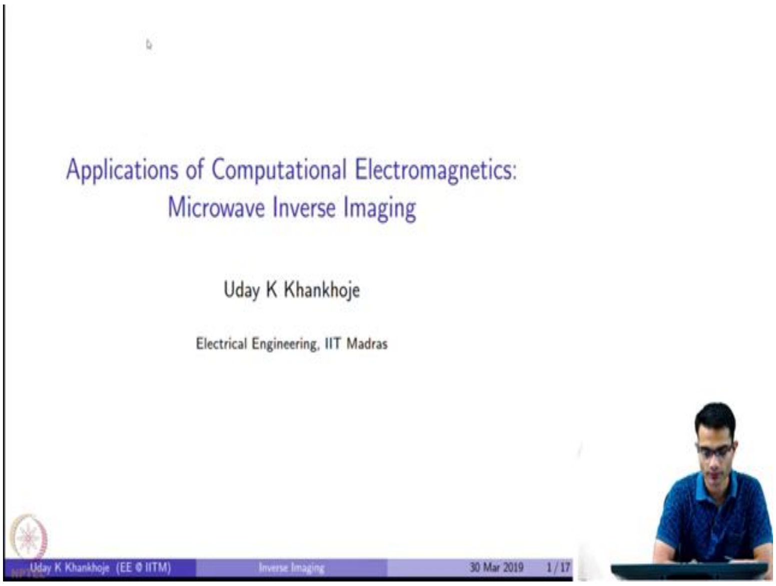

So in this module we will be talking about some of the applications of Computational Electromagnetics and in particular an interesting area of research called inverse imaging ok. We have all heard the word imaging and usually we think of you know a camera taking photographs, but now the question is can the same thing sort of be achieved using microwaves?

That is what we will try to explore and we will see what are the advantages and disadvantages and some of the challenges ok.

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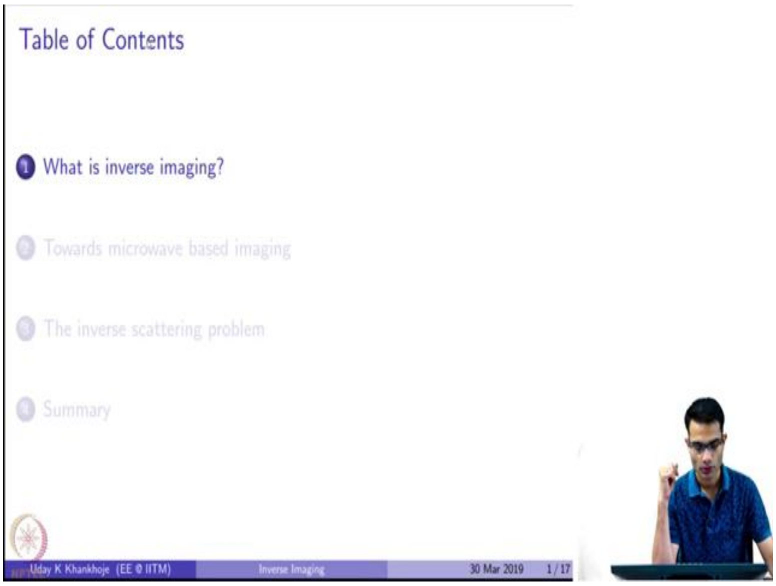

So, first of all what is inverse imaging right.

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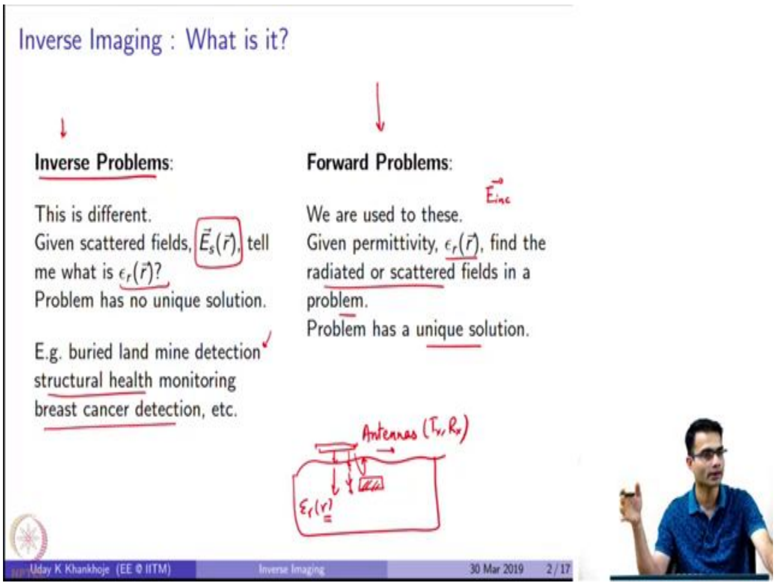

So, you have looked at this course so far has been entirely about forward problems. When I say a forward problem what do I mean that, you know your given the permittivity let us say your also given the E incident.

These two are given to you and you have to find the radiated or scattered field right; this is what we did in integral equation methods, finite element method and finite difference time domain method right. And, we also know that you get a matrix system of equations which has full rank and therefore, it has a unique solution ok. So, there is also a uniqueness theorem which you have studied in the earlier modules, which tells us there is a given certain conditions that the unique solution.

From an engineering point of view, the more interesting problem is what is called the inverse problem. So, what happens in the inverse problem? I am given the scattered field. So, this is what is given to me and the question is: what is permittivity as a function of space. So, there are at least you know three different kinds of examples where this is useful. For example, buried land mine detection; so, let us say you know you have some ground over here, you have some landmine buried over here and what you have is some kind of a sensor.

So, this can be thought of as a like an antenna array. So, they are sending fields everywhere, and what happens is when it hits this object right some of the fields will get scattered back, and this antenna both transmitter and receiver both are there. So, what it is doing its, you sort of take it over the ground and collect the scattered fields and then you solve the mathematical problem assuming you have not being blown up already, to get what is the permittivity as a function of space.

So, this epsilon r as a function of space is very important. If I am able to get this in this domain; that means, I have got an image of epsilon r relative permittivity. Now you know typically these landmines are made out of different material right. It could be a metal, it could be plastic explosive or whatever is different from the permittivity of mud. So, it should show up as something different.

Than I can say he looks like there is something unusual over here take it out right. That is one application; other application could be detecting for example, what is called structural health; so, structural health of what? Could be anything it could be for example, you know some bridge or cracks in concrete that is what civil engineers use these kinds of applications; let us say I have some structure and I do not want to I cannot open it up right. Let us say there is a load bearing wall I cannot you know open it up to see whether is a crack in it or not.

But if I can get ε_r as a function of space, then I can see oh there is a crack running to it. So, that information is somehow there in the scattered field and I want to get it back right and one other very interesting problem is breast cancer detection. So, I will talk a lot about this as we go forward ok. So, how its possible and etcetera etcetera ok. So, is the set up clear? What is meant by inverse imaging? Inverse because it is an inverse problem.

Imaging because we want to get an image of permittivity and permittivity may be complex does not matter, I will get a real part and I will get an imaginary part. So, that is what inverse imaging is.

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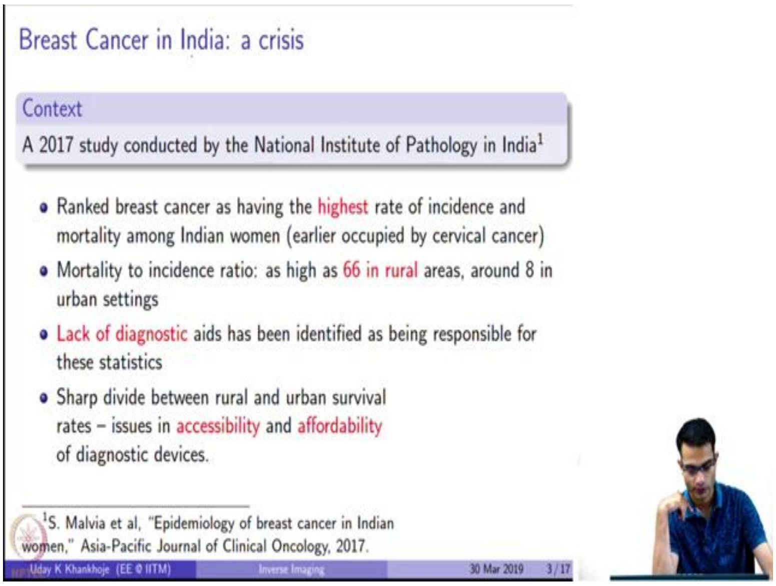

So, as I have said we will talk more about breast cancer right. So, this is just some facts which we should all know. So, there was a study done by AIIMS in India very recently and the rated breast cancer is having the highest rate of both incidence and mortality amongst Indian woman.

Earlier it used to be cervical cancer, now it is breast cancer and we have all heard amongst are you know extended families, in friends circle some one of the other has got it in recent times and what is very alarming is that there is a ratio called mortality to incidents. So; that means that if 100 people got this disease, how many died? So, that number in rural areas is very large, 66, in urban areas it is much less it is 8 right, it is a huge difference between rural India and urban India and. So, that study also identified one of the main reasons was a lack of diagnostic aids.

There is not enough screening that is happening and by the time you detect it many times it is too late right and why is there such a big difference between the rural and urban India is simply access and affordability of some kind of diagnostic tool that can tell catch this early on ok. So, this is sort of facts information right.

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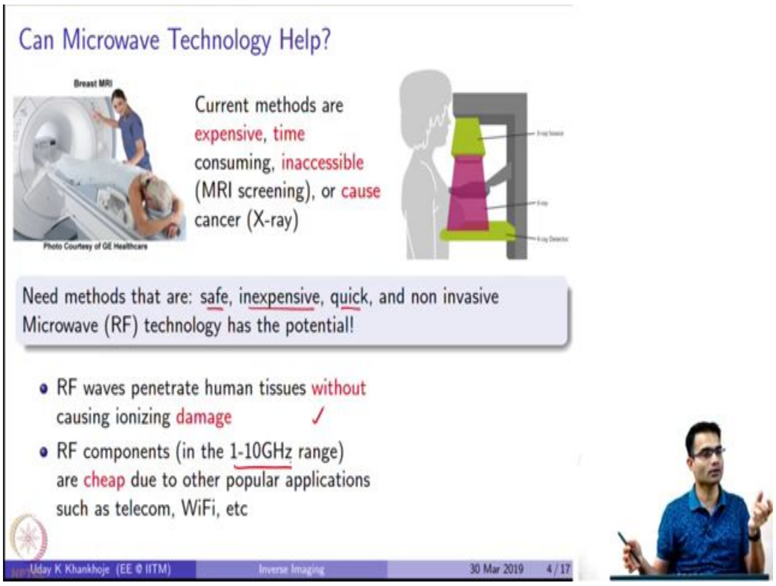

So, let us look at how things are done currently. So, one is of course, MRI we all have heard of the wonders of MRI technology right. So, it produces very accurate and sort of precise images of any part of the human body, not just breast issue but any right. And that is one way and the other way is shown on the right is what is called an X-ray which is also something you are all familiar with right. Now, both of these methods if you can see so, let us talk about MRI.

Of course, it is expensive, not everyone can afford it and it takes a lot of time right it is not just the time in the machine, but the preparation time for the patient everything getting it done. And all its time consuming, and its organ something that is limited to rural I mean urban centers where such expensive equipment is there, you cannot have you know think of having an MRI machine in every village. You do not even have the electricity supply to give a sustained operation of this device right. So, that is the problem with MRI. What is the problem with X-ray?

Student: Radiation.

Right. So, X-ray is cheap I mean it is not that expensive you can imagine having it in many places in the country, but the problem is that it has, it causes radiation damage. So, that is why doctors will say do not get too many X-rays done you know you know given period of time, because the more you expose to X-rays the more the genetic mutation can happen. And, although you are trying to detect cancer you may end of getting cancer because of getting very frequent X-rays.

So, here is the question that can microwave help us in anyway right. So, of course, we need methods that are we have to be safe means no radiation damage, and if this big divide between rural India and urban India has to be bridged then it has to be inexpensive quick. Of course, non-invasive is something that everyone wants right. I do not want to have a biopsy done every time I want to check for this right.

So, non invasive is a nobody and that we want noninvasive right. So, the claim is that microwave or Radio Frequency: RF technology it has the potential for at least these two reasons; the first reason is that RF waves can penetrate human tissues and not cause permanent damage. So, we have been it has been at least what 2-3 decades since we have been using cell phones. So, there it is not I mean if it were really-really unsafe known would be carrying cell phones in their pockets anymore.

There are reported cases of people whose have spent a lot of time close to base stations where the radiated power is much higher and that has known to cause some health effects that is another thing. But when I am talking about the radiation levels from a phone it is ok, it is not something very dangerous for us. So, we know that they do not cause damage right. So, that is safe, the safe part of it.

The other part is that the components are very cheap. Why? Because well telecom you how much you get an ordinary set of mobile phone for these days? The most ordinary phone you can get for 1000 2000 rupees that tells you that the RF components: the transmitter, receiver and the RF circuitry inside is cheap otherwise how could you get at that price Wi-Fi every place we go to has a Wi-Fi right and Wi-Fi works at what frequency? 2.4 gigahertz right.

So, in this range 1 to 10 gigahertz you can get off the shelf components that are inexpensive right. You do not have to design it. You can just buy it.

Student: So, what is the frequency range for imaging applications?

Good question. So, what is the frequency range for imaging applications? So, as I have mentioned over here, we keep it roughly in the 1 to 10 gigahertz range ok

Student: What about terahertz?

So, as you go to well will come to terahertz, terahertz has other problems it is to make a source that can generate terahertz is itself a challenging problem. So, a terahertz sources are themselves expensive. So, you are whole one of your main goals was to keep it low cost, you do not want to defeat that by having a very expensive source. So, you know source is expensive or detector is expensive and all of those things, then at some point you will be like (Refer Time: 09:49) as well do MRI right.

It is true the terahertz will give you better resolution and in fact, there are these airport security that the US has where they have a terahertz scanner, full body scanner, which shows you the presence of various objects right, but those are very expensive equipment.

Student: But for at this terahertz as less penetrating equity right.

Right. So, terahertz of course, has much less penetration depth. So, microwave frequencies in this 1 to 10 gigahertz we can hope that I can get through and through pictures of the body and components are cheap ok. I do not want to go too low because as I go to lower frequencies what happens to the wave length?

Student: Increases.

Wavelength increases. So, I will get an image, but it will be very lower resolution right the imaging resolution is dependent depends directly on the wavelength right.

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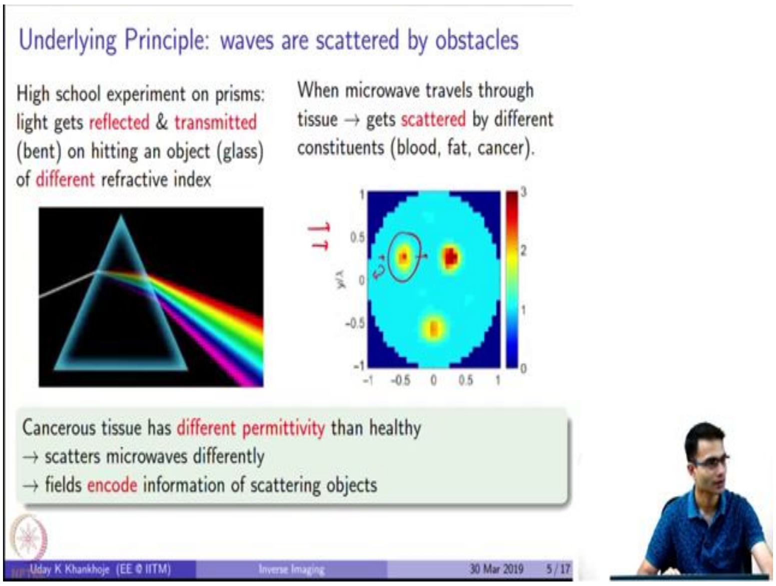

So, what is the sort of underlying physics that tells us whether or not we can image? So, everyone has seen in this experiment in school right you have a prisms and light through it and light gets bent right. Now, the precise is in why light gets bent is because all the colors have different refractive indices that is the more detailed explanation.

But what you can see is, why did this beam of light get bent in the first place? Because it encountered a different medium different refractive index right that is what causes the wave to scatter or in this case we will say refract right. Now, the same principle I can apply to microwave radiation right. So, this is an example just sort of cooked up example of a cross section of let us say breast tissue, which is given by light blue and it has various components ok.

So, those components these are synthetically generated, but they could correspond to something you know some fact tissue and cancerous tissue the light blue could be for example, blood all of these things. So, what happens is when I send a wave through this medium, every time it encounters different refractive index or different permittivity that wave has to undergo some kind of scattering we have seen that.

Now, we will collect back the scattered field process it and try to get an image that is the idea ok. So, more precisely means it is known. So, biologists have done this. They have extracted cancerous tissue and they have extracted healthy issue and they have studied the microwave properties. So, they have studied the permittivity of these tissues. So, of course, cancerous tissue has different permittivity from healthy issue that was the first conclusion right.

As a result of which its scatters the electromagnetic field differently and that information somehow gets then encoded into the scattered field. So, you can imagine in this case and I am sending some incident waves over here if this I have this blob over here, if this blob were not there what would happen to the wave from here? It would just go straight through and through, but now because this blob is here sound wave gets reflected back right. So, this information indirectly is being encoded into the scattered field. So, the information is there some of you have to pull it out.

Student: So, reflection will occur from healthy tissue also.

Reflection will occur from healthy tissue also correct right. So, he is right that reflection will happen anytime there is a change in refractive index right. So, we will talk about how we will distinguish between healthy and cancerous tissue.

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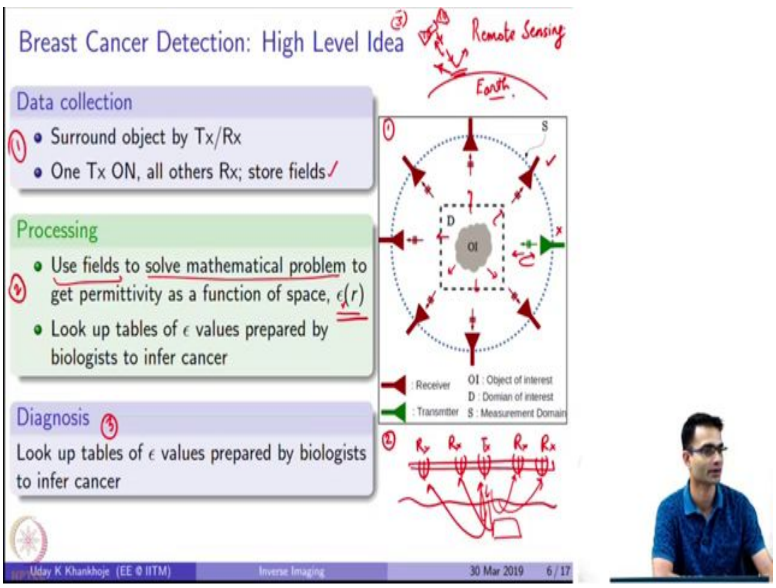

This sort of brings us to the setup of for breast cancer detection ok. So, let us go over it step by step ok. So, this is sort of step 1. So, here I have this capital D over here is showing domain of investigation ok. This could be you know cross section of your head, cross section of breast or could be a tree trunk could be anything.

So, I am saying anything inside D is unknown I want to determine what is the permittivity. So, what do I do in the ideal scenario? It surround this object by bunch of transmitters and a bunch of receivers. So, each of these things can act as both as a transmitter and receiver. So, what I do is, I send an incident wave from here this will get scattered and collected by everyone all of these guys right. So, I have got one incident field so, many reflected or scattered fields then I switch it off and turn the next guy on.

So I will turn this guy off, turn this guy on and repeat the same experiment. So, because the object need not be symmetric rotationally, I will get different information when I am seeing it from different angles. So, all of this information is stored and now the physical experiment is over, there is nothing more I have to do. Data collection is all I need to do because its non-invasive I am not going and cutting or prodding or anything like that and step 2 is where the real challenge is, right.

So, I have to use these fields that I have collected and solve a mathematical problem, this mathematical problem is what is called in inverse problem to get permittivity as a function of space. So, I want permittivity as a function of space. Now as was mentioned it can happen that healthy tissue will also scatter waves cancerous tissue will also scatter waves. So, after having done all of this, what do I do? So, that is actually brings us to step 3 the diagnosis part.

So, biology and medicine people in biology and medicine they have already done the hard work. They have calculated permittivity for healthy tissue unhealthy tissue blood fat cancer all of this thing is tabulated. So, once I have got my this epsilon as a function of space, I just look up each pixel what is the value epsilon, what is the nearest fit? Is it fat, is it cancer, what is it? Right so, that is how I can do a diagnosis of whether or not there is cancer. Can you repeat this experiment using backscattered field only? That means, you just want to use one transmitter and receiver?

Student: Yeah instead of this supplier arrangement.

Student: Can I use this lobo transmit and receiver in single side?

That is what. So, you are saying that I keep this transmitter on, none of the other receivers are there and I just collect this field.

Student: Yes.

Yeah you can do that.

Student: Also.

Yeah ok. So, maybe I will turn it around to you. So, supposing I was doing breast cancer detection there. So, I mean what I am showing you is actually a top view of what the device will look like. So, the patient lies down and there is a like a cylindrical chamber and into which the patient is slightly lowered. So, patient is surrounded on all sides by transmitters and receivers and you collect the field over here. Now, just thinking intuitively if you wanted to solve this problem and would you rather have so many receivers or would you have liked the suggestion only one transmitter and receiver. So, one transmitter sends and you collect back what is coming to you which is better? Everything need not scatter back.

So, if you have the luxury it is better to put transmitters everywhere I mean receivers everywhere so that you can collect all of the information that does not come back to the transmitter. I mean the dimensionality of the problem has not yet been set right now this looks like a 2D problem, but at right I mean it could be a 3D problem. So, I could have multiple layers of antennas receivers and transmitters. So, then I have to solve a 3D inverse problem, but the way I have shown it for illustration it looks like a 2D problem, it need not be ok.

Now, so this is for breast cancer. Now for something like landmine detection there; obviously, I cannot have receivers under the ground. So, what can I do over there? As an engineer of what you know that you are losing information by not having receivers everywhere. So, what would you do?

Student: (Refer Time: 17:51).

So, one answer is that you have no choice, you have to live with backscattered field; is that a better way of doing it?

Many antennas right; so, if I have this is the ground and this is my device over here. So, let us say I have one transmitter over here, what prevents me from putting. So, let us actually let us not call this is a transmitter. So, let us call this is the transmitter. So, let us call this is the transmitter; what prevents me from putting more receivers over here? Nothing right so, this guy sends a wave and it also collects back the backscattered field, but I mean if there is for example, slightly angled object over here.

So, this field will also go back to these points, more information is always better. So, if I were doing landmine detection I would do this. So, it is a half space right I have access only to half the space. So, I should put as many transmitters and receivers as is possible given size, weight and all of these things ok. Can you think of an example where you do not even have that luxury? It is a very important and well known example.

An example where like here; so, we started with example 1 breast cancer detection, I could surround the object very good. Then we came to example 2 where I could not surround the object, but still I could would more receivers.

Student: Air plane.

Airplane right. Little bit more general than air plane is?

Student: RCS.

Student: RCS.

RCS, no yeah well RCS, but application wise

Student: Military.

Military and general space based remote sensing. I mean every country launches its remote sensing satellites to sense the earth right. So, there you know you have the earth like this and you have one turn one your satellite is over here right, its sending a radar wave. So, I am not talking about a passive satellite which just takes photographs, I am talking about a radar satellite. So, it has a radar it sends a pulse right. Here it sends a pulse of course, the wave is going to get reflected back in all directions depending on what is on the ground, but it is a radar in space.

So, do not I absolutely do not have this luxury of having a swarm of radar satellites at the same point in space and time to collect; so, here I have access only to backscattered information. So, this is in some sense problem 3 is the most challenging problem because, I have very little information yet I want to try to map the whole earth ok.

So, the basic principle is the more you limit yourselves the harder you make a problem. So, before designing something try to maximize how much information I can get in a given scenario. For example, cracks in the wall right, if it were a column then I have the luxury of surrounding, but if I have a huge wall then it is like problem 2 then I cannot go around you know around it.

So, then I will have an array of transmitters receivers in the same plane right. So, it is up to you as the engineer how you want to do it. Let us just write it over here, this is remote sensing. And, this remote sensing could be from space, it could be via an airborne radar as well which is more common in the case of military application, you mount the radar on an aircraft.