Advanced IOT Applications
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Lecture – 05
Localization using IMU sensors – I

The topic is about Localization, but this is indoor, say you have an indoor application and you are trying to let us say try to reach a position or a location, not position a location in inside an indoor, large industry or a large building complex. Let us say there are multiple floors and in these multiple floors, there are certain designated locations where there is a cafeteria, there is a library, there is a particular laboratory ok, there is a testing center things like that. So, these are designated locations within not only within a floor, but also within the complete building.

So, let us scale down this problem and just look at one floor where such locations known locations are there, plus there are also let us say office rooms and your own sitting cabins which are there and so on and so forth. This is a large building complex and therefore, someone wants to locate you will obviously have to find where you are in real time because he has just come from outside and he is trying to locate you. One way is you make a phone call and you ask him where he is and he tells you I am in the third floor cafeteria ok. Often we spend time in cafeteria right. So, you may find him in the cafeteria.

Now the question is how do you reach third floor? Where is the cafeteria so on and so forth? Let us also assume that there is an app for that particular building and you have just entered. So, the last GPS coordinate kind of is known to you and after that you want the app to navigate you to exactly the point where this person is to be found. It could be a cafeteria or cabin as I said. So, this is the thing.

This is one problem. One thing that you may want to use localization and when you say it is within a building, you do not want to depend on GPS; maybe GPS is not available. You want to get located, you want to reach a location.

Another motivation could be that you are in a building and you are and there is a catastrophic event within the building. There is perhaps a gas leak or there is some section of the building which is on fire or there is a certain collapse of a certain section of the building and it is important for you to evacuate the building. Often there are let us say hundreds of inmates inside the building at an instant in time and these people have to vacate. They have to come out of the building at the earliest. There is so much of panic, there is so much of confusion and sometimes there is no power.

Let us make one assumption that often we have a smart phone with us and this smart phone app that is running on this system is able to tell us in real time, how to exit the building. Given this catastrophic event somehow the smart phone app detects that there is fire in some part of the building in a particular floor in some part of the building and gives you a safe guidance out of the building, which is a nice thing right you do not have to worry about any panic situation. Just follow the app arrows, like the famous Google maps when you are using it for navigation inside a car, it should be as good as that right.

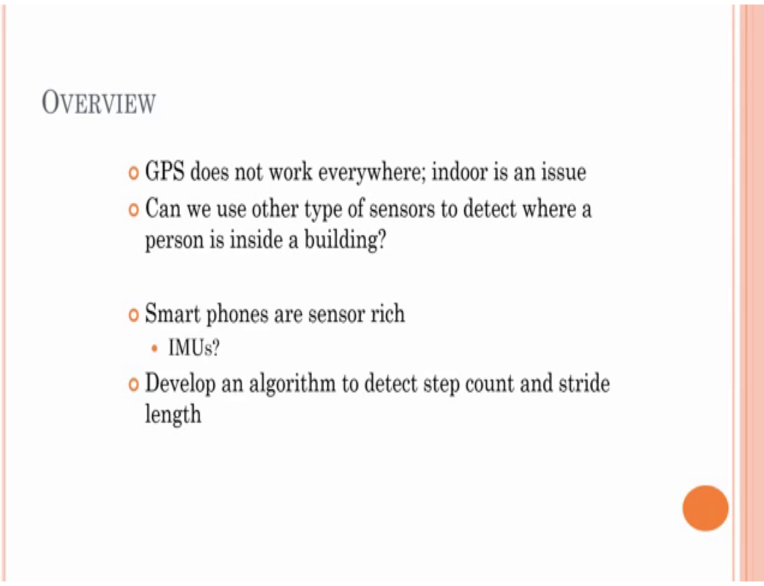
So, both these applications will require surely you will need some sort of assistance from sort of the smart phone and the associated sensors within the smart phone.

Now let us explore use of these IMU sensors, Inertial Measurement Unit systems to build an application.We will have to go through the critical steps in building such an IOT application. You can keep any application in your mind it could be:

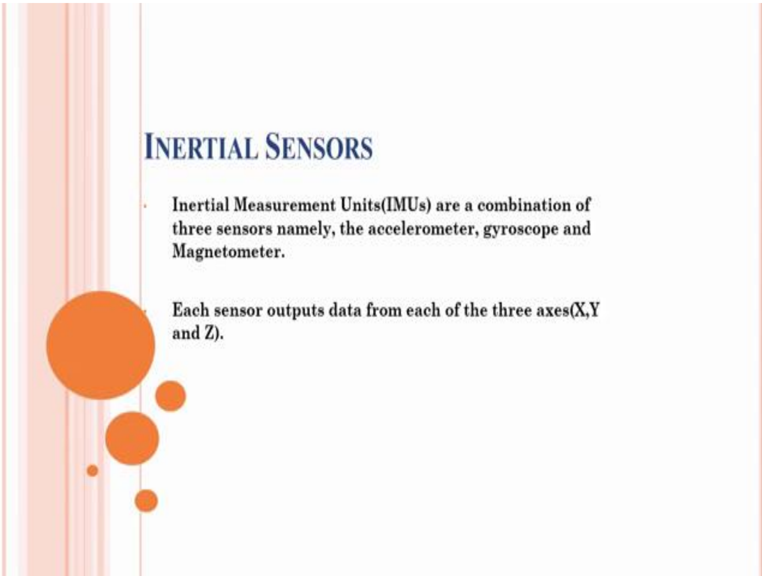
a. trying to locate a person inside a building

b. how to come out of the building in the event of a catastrophe

Both are good applications and you can design applications based on these IMU systems. So, let us look at IMU base localization as an IOT application



So, if you come to IMU's you will see that GPS is the usual problem. We are not looking at working with the GPS anymore and we are looking at how one can use these IMU sensors to detect people inside a building, find out where a person is inside a building and so on.



IMU sensors are a combination of 3 sensors having different principles of operation; one is an accelerometer, the other is a gyroscope and the other is a magnetometer ok.

What are these basic sensors and what is their working principle? The key is that inertial measurement units IMU's as it is shown here consists of one or more of the sensors as I mentioned, measuring change in kinematics of a moving body. So, it is change of kinematic of moving bodies that is being sensed and you basically look at if you leave magnetometer out for a moment because it has other applications, you just look at these two, accelerometer and gyroscope sensors; gyro essentially gives rotation rate of the body ok. So, that is the key here and accelerometer provides information about linear acceleration of the body all right.

So, very clearly they have different requirements and if you talk about 3D motion of a body, you need 3 axis accelerometers and you need 3 axis gyroscopes right. The essentially you when you buy when you have you know have IMU’s embedded in phones, they will be talking about 3 axis accelerometer because we talked about 3D motion essentially.

Usually the axis of the gyro and the axis of the accelerometer are coinciding ok. That is your starting reference point; both the axis are usually together. Normally they coincide; that means, example is in a 3D orthogonal coordinate system, there are sensors to measure linear accelerations on each of these axis and rotation rate of the same axis. So, that becomes easy for you.

So, that is a major advantage of these systems, but you will also have to note that how are these sensors and how do you relate these sensors to what is embedded in your phones.

So, when you say axis, you must have 3 axis right. So, what are the 3 axis? X, Y and Z. If you hold this phone in your hand and move forward, there will be a dominant axis which will give you some data and that data if you take and process you should be able to find out where you are using some dead reckoning based mechanism.

When you say dead reckoning, you essentially estimate the current position from a known position that is you are in some position. You take that known position and estimate the step length, the stride length and so on and then, find out the current position using the previously known position. So, that is what we commonly called as the commonly known as the dead reckoning based method.

So, we can use very simple dead reckoning based methods to actually estimate the current location. All these sounds fine, but the trouble with these sensors which are IMU sensors these are MEMS based sensors inside are if you do any measurement using these sensors, the key that you have to keep in your mind is which is is with respect to these sensors is the accumulated errors. So, this is a nightmare and there are several papers which talk about how to come out with smart algorithms which will sort of compensate for the accumulation errors that are associated with these sensors.

One way is to see one turnaround is do not do integration at all with the accelerometer data that you have. Suppose you are interested in estimating velocity and distance, you will have to do one integral for estimating the velocity and you have to do one more integral for estimating the final distance. Do not do integration; is there anything else that you can do without using integration.

Well, that is if you have to do finding out current position using accelerometer and using this double integral method, you have no choice you have to somehow look for an algorithm, which will sort of compensate the accumulated errors.

Another approach is let us say I take the raw accelerometer value and find a signature from it, that signature I will use for in a smart way and then I will estimate the current location ok. One is just use the data do integration for distance, one integration for velocity and the other integration for a double integration for getting the distance, you can do that that is one way. Otherwise the other way is, take the raw values and do some amount of processing on them.

So, let us see the second approach. Let us observe the second approach of trying to estimate the current position. Why second approach? Because we are talking about building equivalent of a pedometer application, essentially counting the number of steps, accurately counting the number of steps a person takes as he enters from outside the building to inside the building and not only counting the steps, but also estimating the distance each step is associated with. Depending on your height..., the step, stride length can change right.

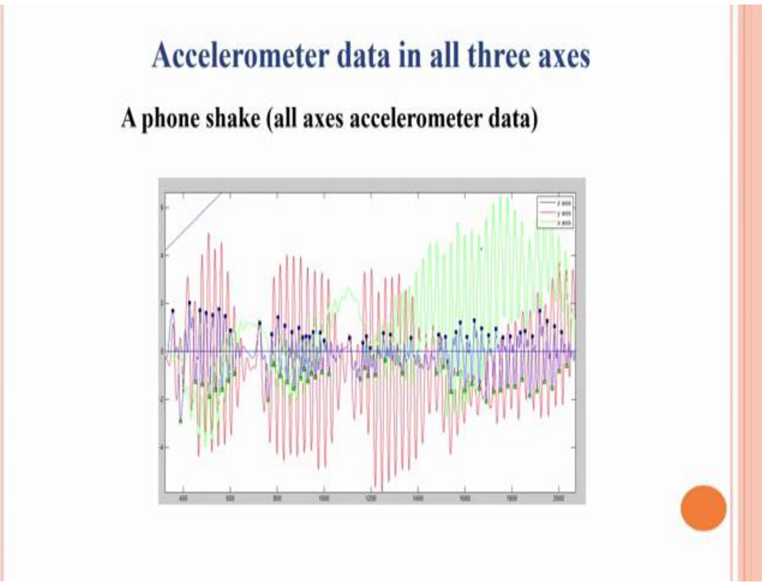
So, some people have small strides, some people have large strides and all that. They say variation of stride length can be as much as 40 percent. So, where is your trouble now? Not in double integration, but your trouble now is this 40 percent variation of stride length.

If you hold phone in your hand and start walking, you will see that the Keeps moving up and down. It makes a very fine movement. So, if you catch hold of the Z axis and look at the signature coming from a Z axis of system, then, Z axis of the accelerometer, then there is a good possibility that you may actually estimate the step length quite well.

So, let us see what kind of result you will get if you actually walk with this phone in your hand. Now its again you can start imagining many things. What if I do not hold this phone in my hand, but I actually put it in my breast pocket? What if I have this phone in my pant pocket, on my trousers?

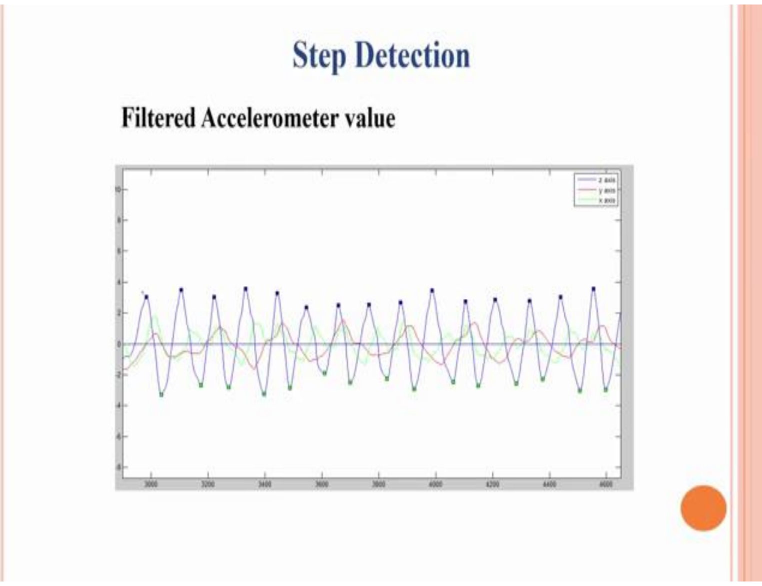
So, in that situation the phone so, then if you start imagining what is actually happening to these sensors inside the X Y and Z direction, 3 axis accelerometer sensors; what kind of signature you get, it is hardly imagine right. So, you will receive some funny waveforms. Essentially what I am trying to prepare you towards is how to imagine what will you get if you hold the phone in your hand and start moving, so that is essentially the suspense towards showing you something very useful. Also this is one part, the other part is what if you hold this phone and for some reason you heard that there is a partial building collapse or fire and all that. Your hands and legs might shake and as a result all the three axis can have a shaky waveform, but then the waveform that is associated with it is because of the shaking of the phone in your hand.

So, you may have to look at algorithms to eliminate the shaking of the waveforms and so on and so forth. So, let us look at some nice pictures, a view graphs and then build a story and then start looking at what are the issues accumulated errors and if it is not accumulated error how do you have the toughen the problem of a stride length estimation and so on and so forth. So, let me just flash my first result to you.



Look at this picture here, there are 3 axis results that you see here; three different colors. This is directly from a phone. The Z axis, the Y axis, and X axis are shown. This is a phone shake of all axis accelerometer data.

From the image we can infer that, a significant peak is observed whenever a step is taken. Each peak is constituted by a maxima and minima. The places where no peak were observed indicates that the person holding phone did not move.

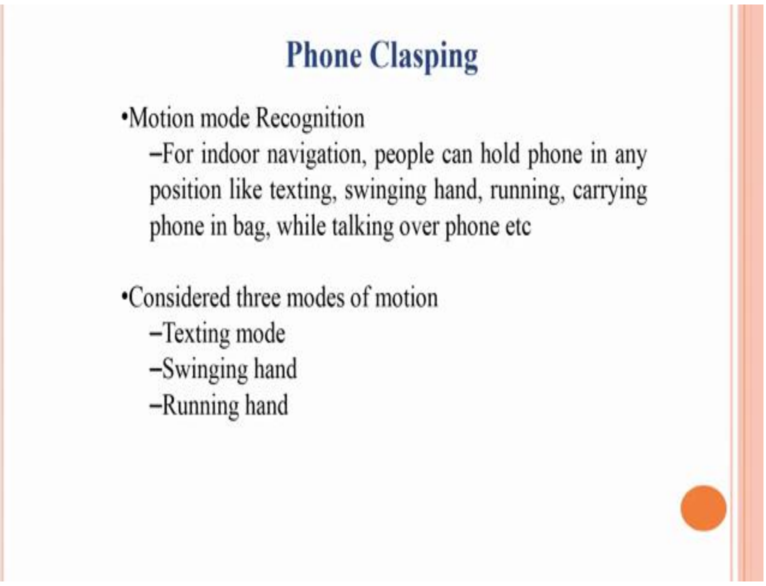


So, this is filtered accelerometer value. This is essentially the 3 axis that you have you can see that the Z axis is the most prominent. This is clearly phone is held in the hand and a person is moving forward and you can see there is a peak, there is a maximum value and the minimum value call it and a_max accelerometer max value and then a_min accelerometer min value.

So, if you start counting the peaks, you will find out the number of steps. So, there are total fifteen steps.

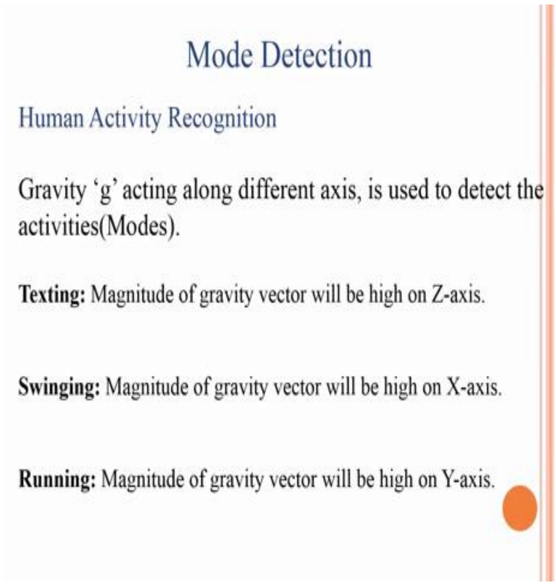
Very prominent Z axis is telling you that there are fifteen steps taken by an individual person, holding the phone perhaps in his or her hand. So, that is you can call it equivalent of a texting mode. The above graph is for a person holding in the hand maybe right hand maybe left hand should not matter. And moving forward, the Z is moving up down up down up down and you can see beautifully that this up down movement of the Z axis is nicely captured.

What you also see which is hidden from this is your problem starts now. What is the stride length between these 2 peaks that is not know. You know that there are number of peaks which is the step count, step detection; but you do not know what is the stride length.



I had mentioned to you about motion mode recognition is an important thing whether you are holding the phone in the left hand, right hand I already mentioned. People can hold phone in any position; can be texting mode, can be in swimming mode, swinging mode, running mode, carrying phone in a bag walking while walking over while talking over a phone; that means, the phone is held against the year and you can do many things.

For simplicity, let us just group all of them into not all, but at least a few of them into 3 groups for major part of the work one can say that it is in either texting mode; that means, you are holding the phone like this or your walk you are holding the phone in your hand and you are moving forward either left hand or right hand, again a very very important or you are running with this phone. These are three things. You can more you can add more as I said and you can look at signatures coming from these IMU sensors to process them and accordingly, you know estimate the current position from known previous positions.



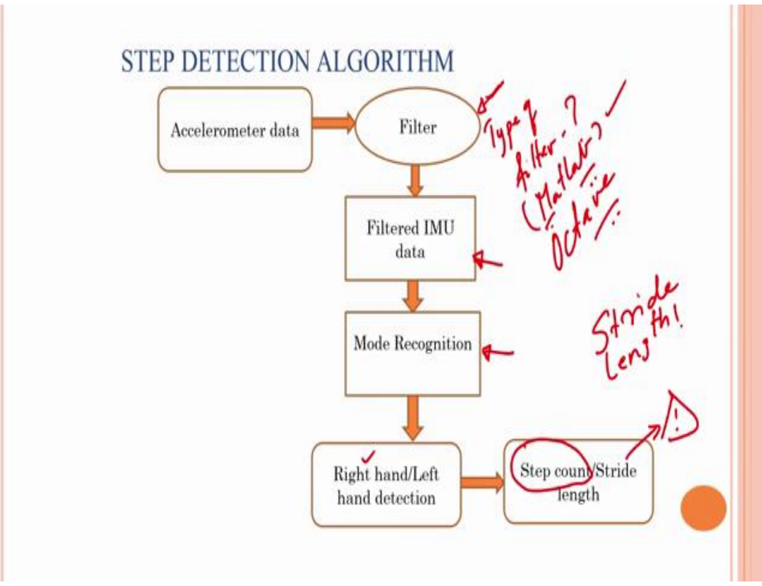
So, these are the three modes. Essentially we are looking at humans who can hold phone; who can hold the phone in any 3 possible orientations, but there are other orient possibilities, but we just limited our discussion to 3 possible ways by which you can hold a phone.

You can hold a phone in texting mode, usually that is what you do when you are doing when you are looking up when you are walking and checking your email and WhatsApp messages etc.

Swinging mode is holding the phone in your palm and moving forward in a basically sort of marching forward.

So, that is essentially your hands are swinging all the time and running is running you hold it and then the elbow is bent and then, you are perhaps running to catch a bus or you are catching trying to reach out to your nearest transport. So, those are the modes which you can think of. Now you need to detect the modes. To do that, one easy way is to look at the gravity vector. Now, if you look at texting mode the gravity vector will be very high on the Z axis.

Similarly on swinging and running mode the magnitude of gravity vector will be a high on the; high means what? its high essentially means it will be 9.8meter per second square. It will be as close to 9.8 meters whichever is the highest means it is in that particular mode depending on whether it is Z, X or Y you essentially can differentiate. So, essentially just look at the gravity vector; find out which is the one that is closest to 9.8 meter per second square and then, decide that it is indeed that mode under which the phone is being held.

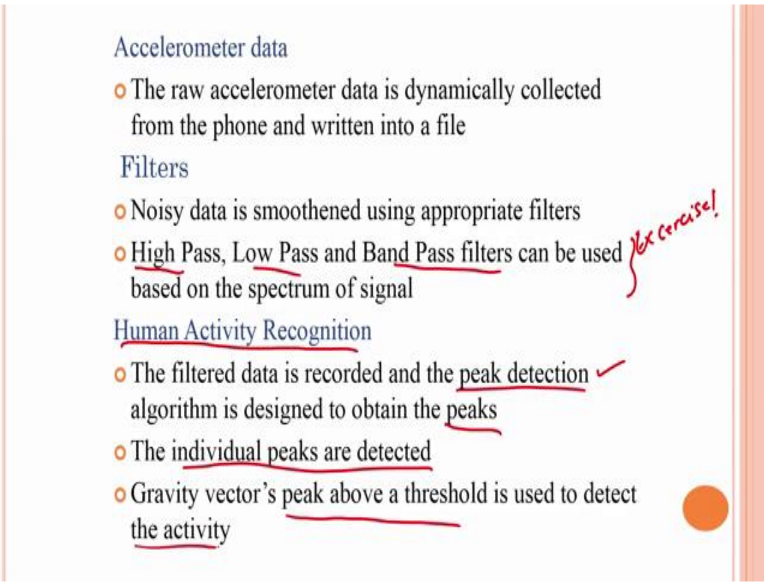


You can capture all of that into this kind of a nice mode into a nice algorithm which I expect you to start designing on your own given some basic scripts and basic files that that will be available to you. Accelerometer data, you have you need a small script to gather it from your smart phone. Filter, what filter will you choose?

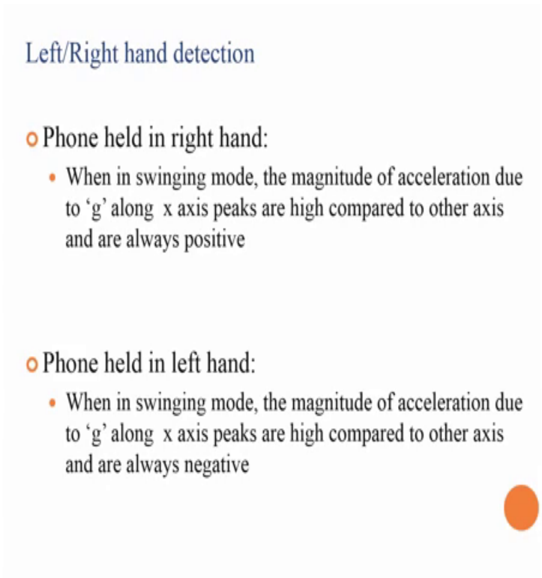
You can apply several filters right, you can apply a Chebyshev filter; you can apply different orders of filters, you can apply a Butterworth filter. So, you need to understand you need to a code each one of these filters and use it for your application.

So, anyway you end up with filtered IMU data and then, you do a mode recognition. In what mode is the phone being held; is it any one of the three that I mentioned to you and in what hand is it in? Which hand; right hand, left hand? Then, you estimate the Step count and this hard problem Stride length. I want to tell you that this is hard because it is an unsolved problem even today.

Stride length, this is the hard problem. Step count you can get very accurately, but stride length estimation is perhaps the hardest problem.

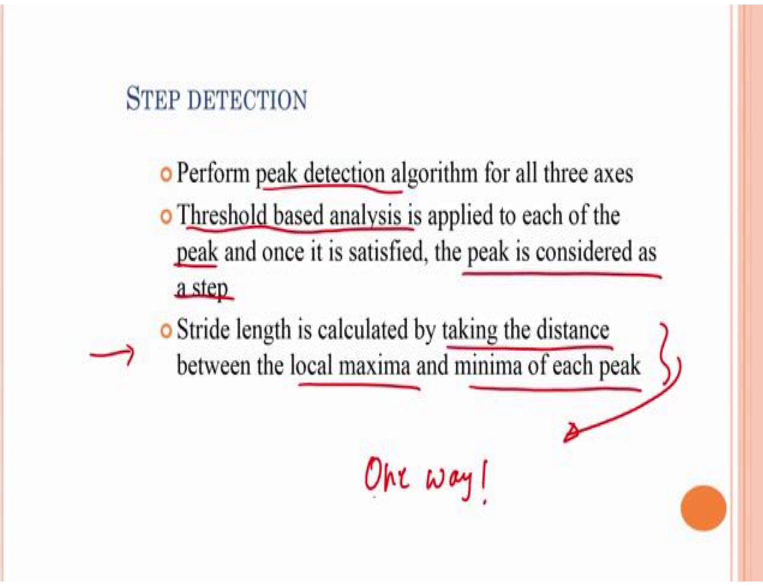


The above slide gives the sequential steps involved in implementing your algoritjm to localize a user indoor using IMU.

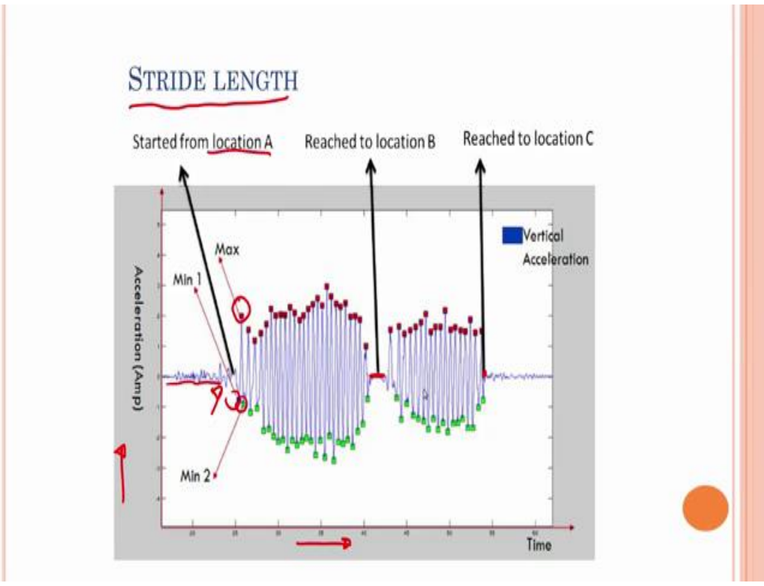


Next is quite simple. You do not know whether you are in you are holding your phone in the left hand or right hand, but it is pretty straightforward for texting mode. But for swinging mode, you can look at phone on the; if you are holding the phone in the right hand, the magnitude of acceleration due to g along x axis is quite high as compared to other axis and is always positive. As far as the phone held in the left hand is concerned , when in swinging mode the magnitude of acceleration due to g along x axis are high compared to other axis, the same as what you have seen in the right hand, except that the difference is the values are now negative . So, that is the key different the key difference between in the swinging mode right hand or left hand.

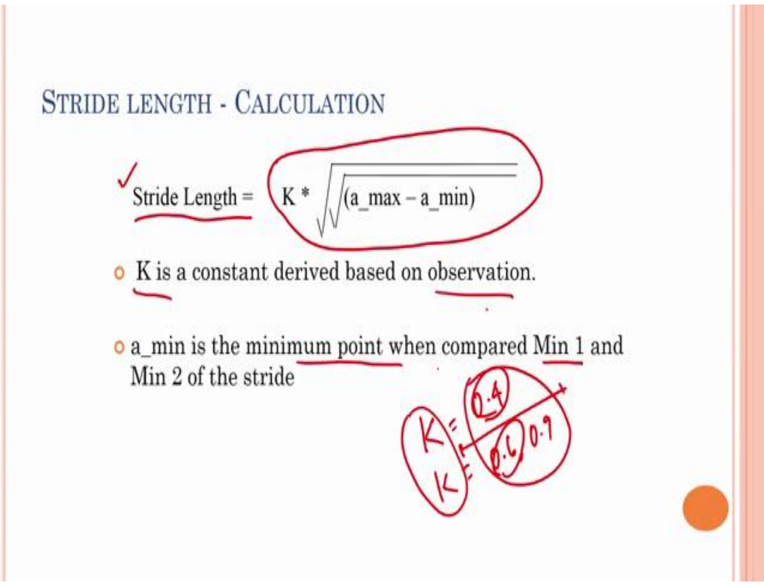
Now, what is it for running mode? I have not put a slide on that and I expect you to collect data and do a little bit of processing and find out what is the way the method that you can adopt for detecting left hand and right hand when you are in running mode.



Once you perform peak detection algorithm and you apply the necessary threshold based analysis to each of the peak, then you considered a peak as a step, and stride length is calculated by taking the distance between the local maxima and minima of each peak.



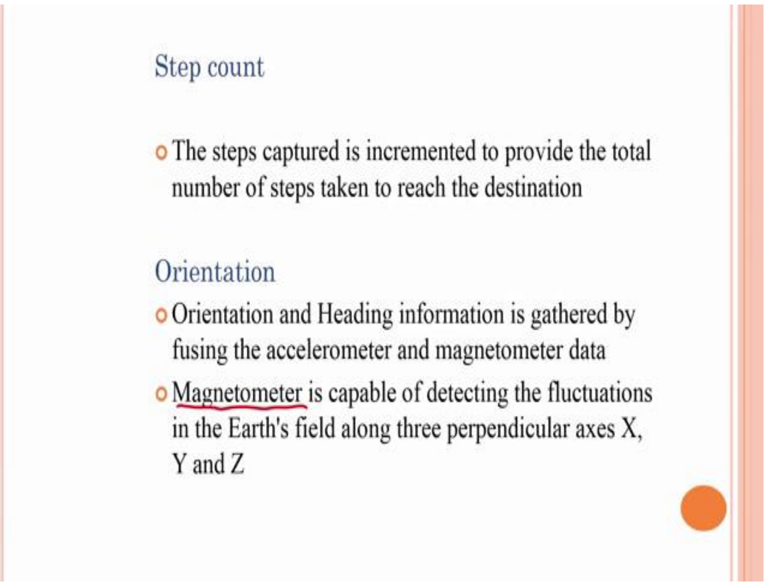
The above image shows the peaks that is the steps taken by a user for going from point A through B to C. The no peaks section at B indicates that the person stood at point B for a while and then moved onto C. The red and green points are the maxima and minima values which will be of interest to estimate stride length, that you will be witnessing in the next section.



The above expression named the Weinberg expression can be used to estimate the stride length. You will have to again try this as a basic expression and try to you know sort of read up literature which I am going to point you to I am going to point you to different literature on how to estimate this stride length. We shall look up that paper and understand it better.

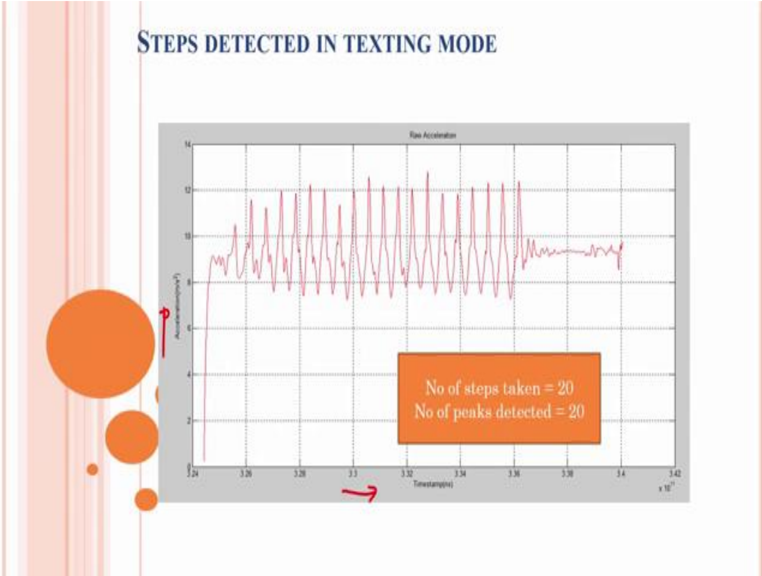
K is a constant derived based on observation; that means, if it is me, there is a certain K value. If it is you, perhaps there is another K value and this K is typically less than or equal to 1 which means it is some sort of a fraction and you can have 0.4, 0.6 I do not know whatever and therefore, it can be any varying. So, you will have to tune it based on observation. But then why is, so you can see now if it works for me, it does not mean it is going to work for you because my K value can be 0.4 and your K value can be 0.6. So, somehow you need an algorithm which will dynamically adjust the K value such that this stride length estimation is very very accurate.

Now a_min is the minimum point when compared to min1 and min2 of the stride and therefore, you have to take the minimum of min 1 and min 2 and use one of them for the purpose of stride length estimation.

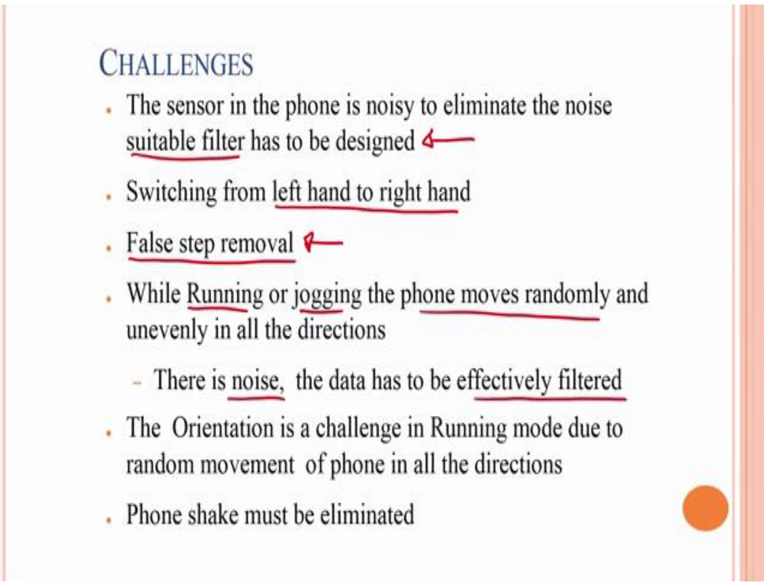


So, step count I have mentioned to you is quite simple, you could get by just counting the peaks. Orientation is another issue because you talk about a building you are not just all the time walking straight, but you are also turning. Inside buildings it can be sometimes a 45 degree turn, but often it is a 90 degree turn.

So, for Orientation you could use magnetometer quite effectively. This capable of detecting fluctuations and you could combine the accelerometer data with magnetometer data in order to arrive at the orientation of a person how as and when he is trying to reach the designated location or trying to evacuate from within a building.



You can see that each mode has its own signatures that you will get. We also said that the unit algorithms for more recognition in any case I am just showing you some data here. These are step detected in texting mode. Again, the x axis is time; y axis is acceleration; number of steps taken is 20; number of peaks detected is also 20.



Now, there are as I mentioned to you other challenges which are associated with IMU based localization. For left hand right hand, you need an algorithm. False steps have to be removed. Sometimes shaking, sometimes some other issues may come which you will have to remove false steps and in the case of running and jogging this phone move will move randomly in all directions. Orientation will have to be taken care and shake in the phone must be eliminated because in the event of a fire or any one of those catastrophic events, humans end up shaking without their own knowledge they may be shaking. So, that faint phone shakes will have to be removed. So, that is in brief all what I wanted to tell you about building an application.