Advanced IOT Applications
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Lecture – 04
Outdoor localization using elevation - pressure mapping

Let us look at another modality by which you can do localization without GPS and these are typical of what you can do with IoT kind of sensors. I will give you a nice motivating example and after that let us see how we can build this application.

Imagine a situation where, let us say a vaccine which has to be transported from point A to point B. this vaccine is obviously you have to store it properly, you have to keep it under proper temperature conditions and ambient conditions also have to be maintained properly and perhaps this vaccine should not take a route which is very bumpy very dusty and so on.

And between point a and point b, you can have multiple paths and now you have told the truck driver or the car driver who is carrying this vaccine that you should take this route and no other route to reach from A to B. The reason why you have fixed this route is because you know for sure that if he takes that route, the vaccine will maintain its potency and it will be useful when it is being administered.

It could be vaccine, it could be anything, just giving you an example. So, you what you do you make it into a small package, put the vaccine inside and then you put some sensor there and then you know sort of load it into the vehicle and the vehicle starts to move. At point b you should have a very simple way of finding out whether the truck driver or taxi driver took the route that you have specified.

This is very important and let us make a very harsh assumption from point A to point B is a root which is lot of tree cover. So, no way by which you can actually depend on trying to use GPS in this kind of applications because of the fact that the root may also pass through several tunnels and all that because just has to maintain that optimal path.

Now, question is what kind of IoT solution can you think of for this kind of motivating example? One thing, look at even mobile phone sensors, barometer is something that is quite common in most high end phones; And it is very easy from simple physics that pressure is highest at the sea level and as you go up the pressure reduces and because binding of these molecules is sort of loosened.

And therefore, pressure is very low and it continues to go lower and lower as you go higher and higher and there are very simple expressions by which one can compute this pressure that is at different heights. For example, pressure in itself can be expressed in several ways and people use different units for expressing it. Some people put it in terms of pounds per square inch; some set of people use kilo Pascal's and so on.

So, let us take some standard way and fix that as a notation before we move on. Actually you can use any simple calculator to find out what is the pressure at sea level. If you do a compute, you find that it is a 101.325 kilopascal at sea level and any number has only be got to be lower than this. So, as you go up plane for instance, when it goes to 30000 feet and all that pressure is outside pressure is very low. And therefore, they have all kinds of cabin pressurizing systems to keep the pressure equivalent of 8000 feet inside the cabin. So, and that means, a lot of equipment to keep the humans properly breathing and ensure that the air quality is good and so on. So, that is another problem; but just to tell you that outside pressures are low. Now it is easy to see that a simple IoT solution means that you essentially do a pressure based profiling.

Now if you have a simple pressure sensor, you do a pressure based profiling and convert that pressure based profiling to elevation and then you have an elevation profile. Now you go back and look at Google maps or any map related information, even GPS for that matter. What will GPS give you? It will give you the lat (latitude), long (longitude), it will give you the elevation as well. It will give you time and so many other related parameters.

So, elevation is available in even from a map. Now you are fixing from A to B based on a certain map information that you have and that is fixed you do not need any access to any GPS satellites or anything because the map is already a onetime activity. It is already done. It is available to you. Now what you have to do? At the receiver at point b you have to take the data that is collected from this pressure which is now converted to elevation, that elevation data is one time series.

This map related information that you have collected from the maps is another time series. Time series or you can say it is a set of points. Time series will come if you know the speed at which the vehicle is moving and all that, but you can also you can obviously calculate the speed at which the vehicle is moving. So, you can actually call it another time series.

So, you have one time series which is coming from the map, I call this the route information-ground truth information available to you and you have the pressure based information which is now converted to elevation information another time series. And use these 2 time series somehow match, map, align them and then arrive at the point where you can decide that the vehicle chose the right route. Out of the given n number of routes from point a to point b it chose that route which was prefixed, which was perhaps the most optimal for carrying that vaccine and it is indeed the route of interest.

So, this is one thing. This is not, it is not that you can do alignment very easily. You need some simple tools like dynamic programming tools like dynamic time warping which is a very simple algorithm, you can use that. And then, align these, do time series and then, arrive at a decision whether the person took the right route. So, this is what the gist of the problem.

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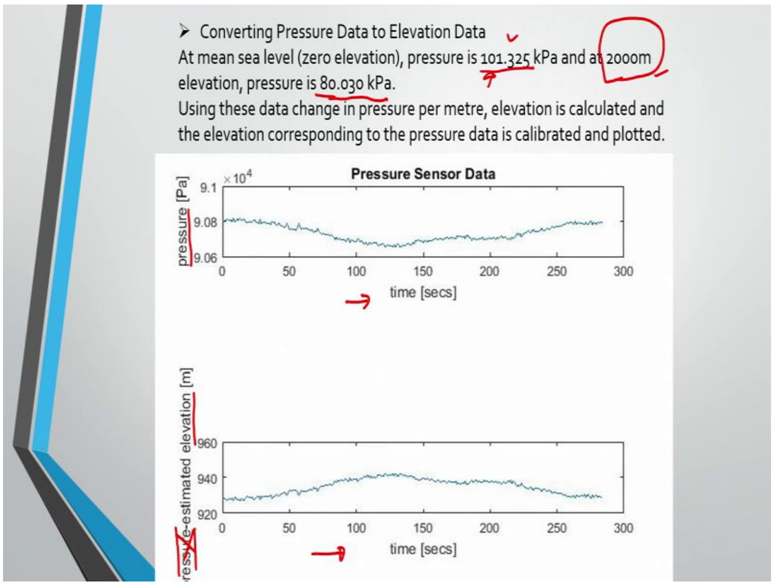

Let me point you to this result here in the above figure. Essentially you are talking about 101.325 kilopascal at sea level and if you use a simple calculator you will see that at 2000 meters the pressure is about 80 kilopascal. I mentioned to you any pressure that you measure has only got to be lower than this value. It cannot be higher because this is the highest at sea level. And then, what you do?

You convert this pressure into elevation and you just see how it looks. On the below graph what you see in the above figure, this is elevation data you can see that it is going up and down and as it goes up in elevation, the pressure has to decrease and this is matching as you go up the pressure is actually dropping.

So, this is something that you can easily conduct with the mobile phone that you have or any other pressure sensor that you have, use the existing map data of your area and you can profile it elevation to pressure.

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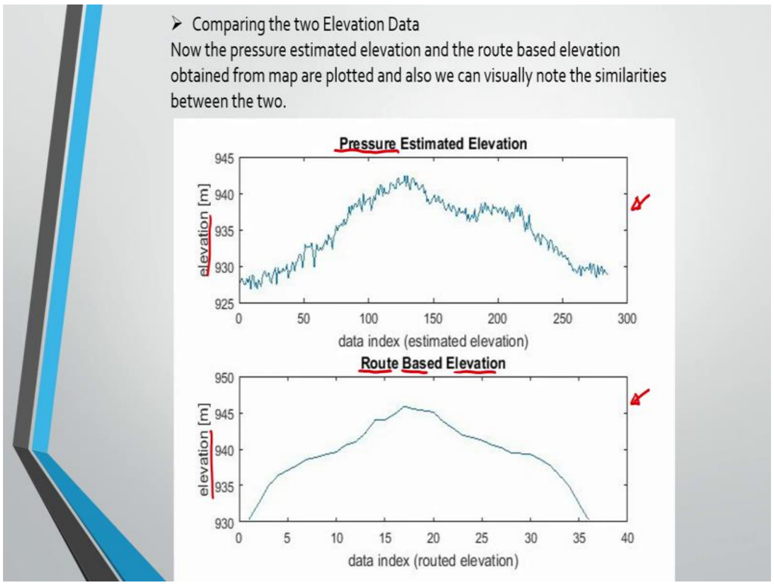

Let us look at the specific example shown above figure for instance. Here again you have elevation which is the ground truth from map and you have the elevation measured from pressure, which is the actual data that you get from your sensors and this is time series essentially.

So, anything that you see with respect to route based elevation means that this is ground truth this is from map. And the good thing is both of them look almost identical, the lot of noise here because sensors as we mentioned earlier are very noisy, you have to de noise; you have to do normalization and all of that before you actually not using. So, lot of I would say preprocessing steps have to be done, before you start doing any sort of time series alignments. So, this is these are all preprocessing steps.

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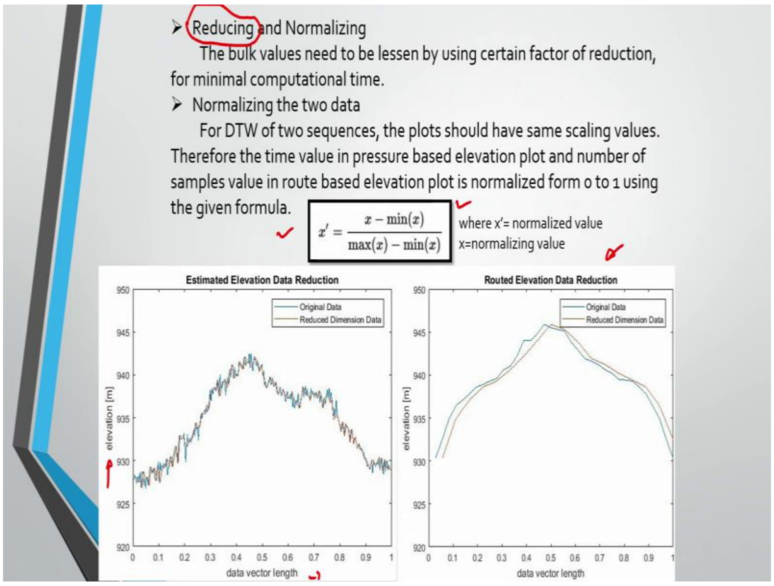

So, essentially it's coming down to that. You do a little bit of preprocessing; you do reducing and normalization. For Normalizing very simple expressions can be used. What is this reducing? See if you put a pressure sensor and you say I want 1 sample every millisecond or every 10 millisecond.

You end up with humongous amount of data that perhaps is difficult to process with any dynamic programming tools. So, what you do is you find a way of trying to prune that data that you have collected and extract very important sections in the time series for the purposes of time warping. So, that is reducing.

Normalizing the data is important because you get data from completely 2 different ways by which you are collected data; one is from the map related and the other is actually from a sensor related. So, everything has to be normalized so that you can actually do the proper alignments. So, the very simple expression here which will allow you to do a normalization.

$$x' = x - \min(x) / \max(x) - \min(z)$$

So, now you see estimated elevation data reduction, original data and reduced dimension data, you can see that you have taken away several samples out of it. So, that it is easy now for us to do a time warping with the reference data. In above figure, on the x axis is data vector length and on the y axis is the elevation and here the ground truth which is essentially the routed elevation data reduction and reduced data dimension and the original data both are shown.

It is obvious that original data is much sharper as lot more points as compared to the reduced dimension data. But that we can live with that because you are trying to get hold of very important key features. It is also important at this stage to note that what is it at what scale at what accuracy you are trying to know you are trying to get to localization. Here it is not like the IMU system where sub-1 meter accuracy may be required.

If you are doing an indoor localization, like examples like fire detection and all you are using a mobile phone using IMUs, a stair case which can be used for coming out of out of the building if your localization accuracy is less than a meter; you actually miss the staircase. Indoor even 1 meter is a lot whereas, outdoor 1 meter may not make much of an impact. So, this application is not really talking about sub 1 meter and all that. It is just trying to come to a gross scale, yet it should be able to do the job of trying to profile the exact route taken from point A to point B. So, you are to note that these are applications of that nature.

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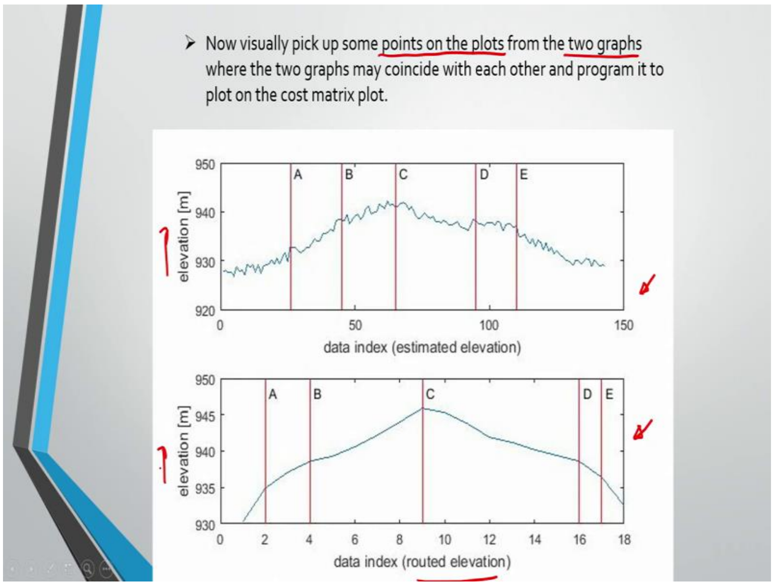

Now, we go on and pull out those important parts of this time series which is dividing this whole thing into sections. So, you visually pick some points on the plots from the 2 graphs wherever they may coincide with each other and then, you use the dynamic programming technique to actually populate the distance matrix.

So, again you can see that this is ground truth, which is shown as routed elevation in above figure. And the estimated elevation from the sensor data. So, you can see the y axis is elevation in both because one is ground truth and the other is sensor based.

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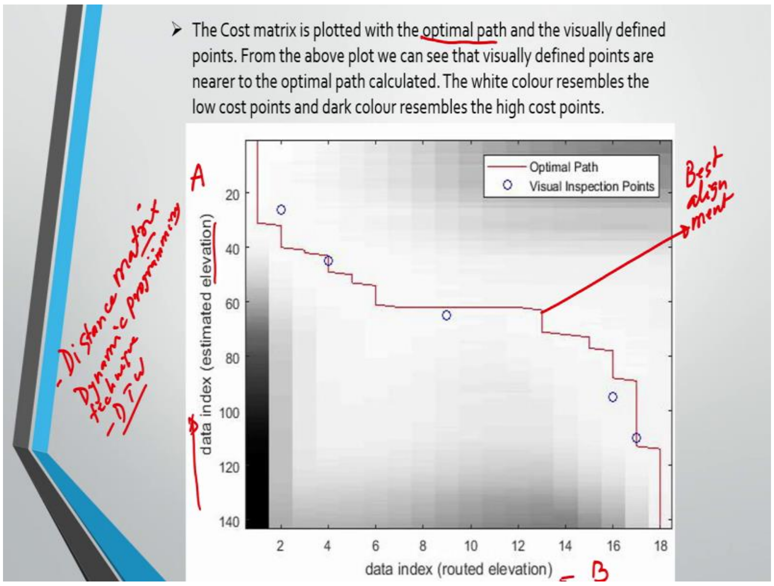

At the end you use the DTW technique and then, you populate that matrix. Matrix, so I would say first step is Distance matrix and which uses the dynamic programming technique; which is essentially DTW (Dynamic Time Warping) you get to the distance matrix and then you come to the optimal path. When you say optimal path, this is the best alignment.

Please note from the pressure sensor we have converted it into elevation and the y axis is essentially the sensor based output and the x axis you see indeed is the ground truth based data in the above figure.

In dynamic programming one can call this y-axis time series as B and the x axis you could call as A. then you get to the best alignment of the two time series and which is essentially the optimal path. It also shows that the white color resembles the low cost points and the dark color resembles high cost points. So, this is the right alignment of the two time series.

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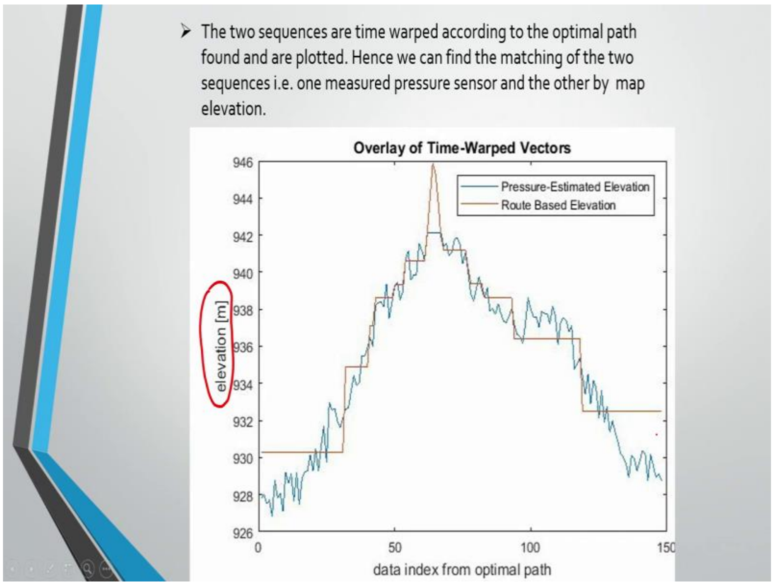

After you do this alignment, pick those points that you got from the alignment and convert it back into the route based elevation and pressure based elevation. You can see in the above figure you have 2 of these elevation, which is one with respect to the ground truth and the other is with respect to the pressure based sensor

You take some points and then you see that it has indeed warped, you do an overlay of the two warped vectors which essentially lead to very accurate identification of the fact that the vehicle indeed took the right route from point A to point B.

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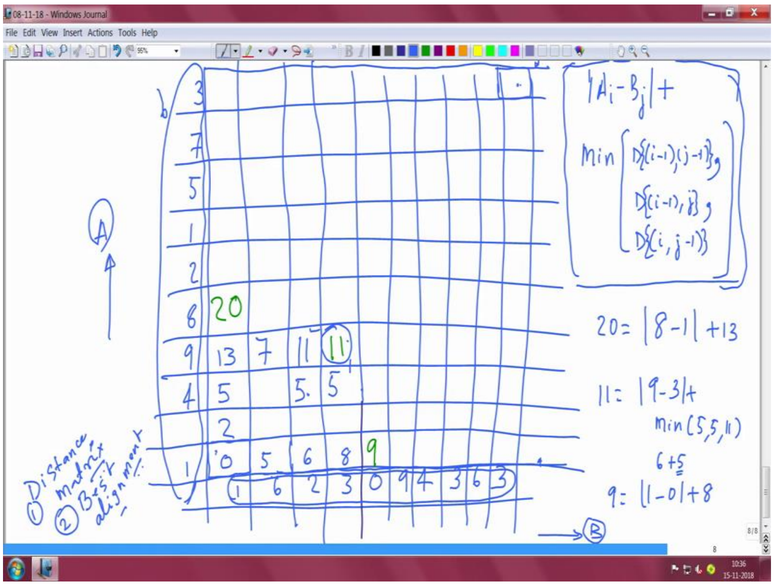

Let us look at a very simple dynamic programming exercise. The very simple one I thought I should show you how this simple technique is a very powerful way of alignment of two time sequences. Let us say the first time series sequence is A which is shown in above figure and the second time series sequence is B. Now the points of this time series is, this that I have in the elliptical form that you see in the above figure

Now your objective is starting with the left bottom corner, which is written 0 in the figure; starting with this square you have to populate till the last square if you populate that you will do a first step which is called the distance matrix.

Then is to find the optimal path. I have not shown you the optimal path in this because I want to just hammer on the first part which is essentially the distance matrix population. Let us say you are interested in populating this particular cell which has value 20. This value 20, you have to critically note is computed using the expression shown in right side of above figure. This expression that you see here is the mother of all expressions.

$$|Ai - Bj| + \min [D\{(i-1), (j-1)\}, D\{(i-1, j)\}, D\{i, (j-1)\}]$$

$$= |8-1| + 13$$

$$=20$$

So, nothing else matters. This expression is what is required for populating it. It says take the mod $|Ai - Bj|$ and take the minimum of 3 previously computed values; Take this 20. What is pre 3 previously computed values for this? Nothing, there is only in one. This is the only one that is previously computed i.e.13. You cannot use other values because this is part of the time series data points. So, there is only one that is previously computed.

Suppose you are interested in this cell which has 11 (which is marked in green, in the above figure); if you are trying to look at this cell, then its previous computations. All the 3 exist for this. Now apply the same logic to get to this filling up the cell.

$$|Ai - Bj| + \min [D\{(i-1), (j-1)\}, D\{(i-1, j)\}, D\{i, (j-1)\}]$$

$$= |9-3| + \min (5, 5, 11)$$

$$=11$$

$$|A_i - B_j| + \min [D \{(i-1), (j-1)\}, D \{(i-1, j)\}, D \{i, (j-1)\}]$$

$$= |1-0| + 8$$

$$=9$$

Now how will you compute the cell which has written 9 as the answer (in the above figure), You can populate this cell based on previous computations, as I mentioned to you previous computation is only one in this case which is 8 and other you cannot use obviously because this is really the part of the time series. So, is you have to start your matrix actually from left bottom corner? So, this is very important often you get confused.

So, you could try populating this complete table using this one mother expression and then you will come up with a nice completion of the distance matrix. Now obviously, this is only 1 part as I mentioned to you. What is important is, to compute the best alignment.

So, after you have finished the distance matrix, you have to come to the second step which is the optimal path, is nothing but the best alignment. It is easy for you if you start from either this corner, some of the time series you will start from bottom left corner and sometimes people start from top right corner. You could start looking up the path from top right corner to bottom left corner and take the minimum values as this comes down.

That is indeed the best alignment of this 2 time series A and B. This is left to the student to actually try out and get to the optimal path of the best alignment of these 2 time series.

This is how a dynamic time warping actually works, is quite powerful in several domains, we will see how this technique could be applied in different application domains.

Thank you very much.