Control Engineering
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Module - 11
Lecture - 03
Part 2
Complementary Filter

Welcome to the lecture on control engineering. So, I will be taking you on to the applications of the complementary filter.

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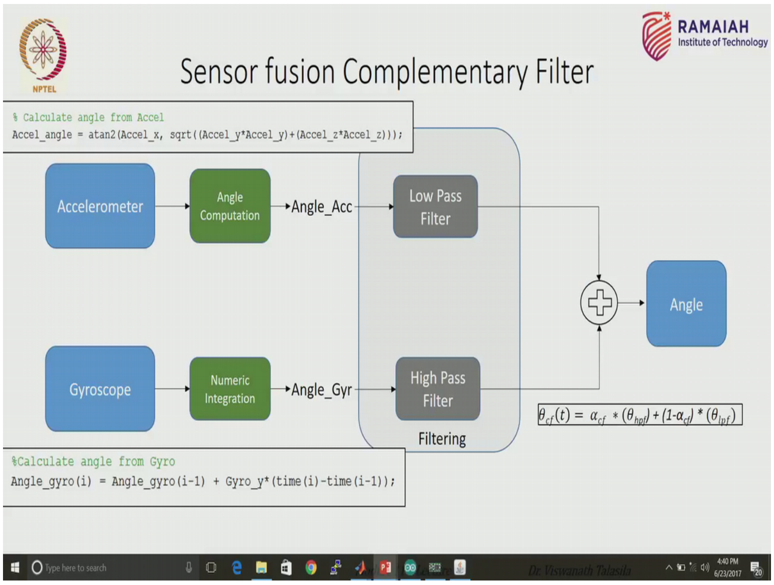

So, the complementary filter is a sensing is a sensor fusion algorithm where we calculate the angle from the accelerometer and then after the angle computation block from the accelerometer, we get the angle underscore accelerometer we pass it through the low pass filter and bring it into the combination block from the gyroscope we also get the angle by numeric integration. The formula for numeric integration is shown below this angle from the gyroscope is pass through the high pass filter and it comes to the combination of the low pass filter of your angle from your accelerometer and your high pass filtered angle from your gyroscope.

So, as discussed previously the complementary filters equation is as follows theta c f is equal to alpha which is your filter coefficient of your complementary filter into the theta of the high pass filter which is the angle which comes from the gyroscope plus one minus alpha c f into the theta which comes from the angle calculated from the accelerometer. So, these 2 are combined depending on the dynamics of the moment that we have the complementary filter equation is this where theta c f is your filter coefficient for the complementary filter theta c f is the angle computed from the complementary filter the theta high passed is the high passed value of angle from your gyroscope and theta low pass is the low pass value of the angle from your accelerometer.

So, I will be showing you the MATLAB implementations of why we use the low pass filter and the high pass filter and how do we combine these 2 angles from the accelerometer and the gyroscope in the complementary filter.

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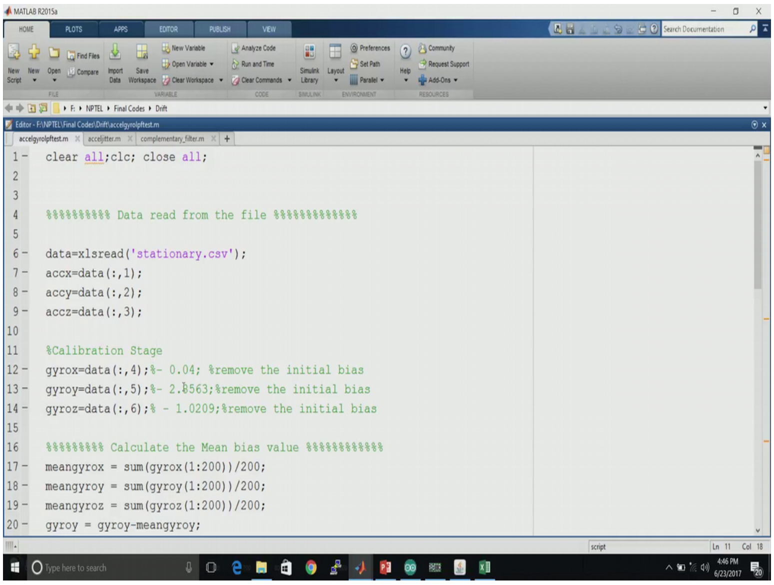

Here are the 3 codes that we have for the actual implementation of the high pass filter for the gyroscope angle and the low pass filter from your accelerometer angle and the complementary filter block which combines the high pass filter and the low pass filter angles in one particular computational block. So, I will show you first how we have the drift in a particular stationary position and how we correct the drift in this particular experiment.

So, here we have a csv file which is in the in the names stationary dot csv I will show you the excel file for that. So, this is the excel file where we have collected data from an

IMU that we have. So, this IMU consist of an accelerometer and a gyroscope where the accelerometer is the ad accel 3, 4, 5 and the gyroscope which is lg 3, 4, 200 d.

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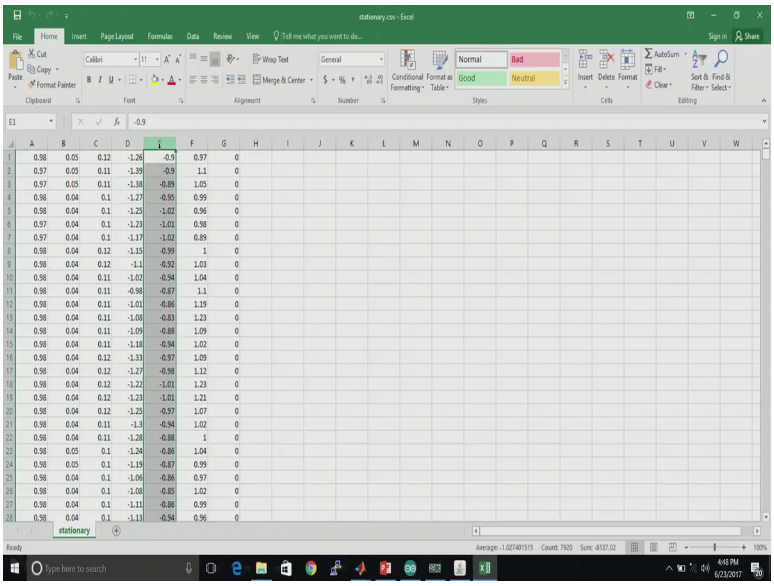

Here we can see that how we save the data is column number which is accel x. So, this is the axis of the accelerometer which is pointing forward. So, if we consider this be the accelerometer and I keep this stationery the axis which is pointing forward is the x axis the axis which is perpendicular in this manner is the y axis and the axis which goes through the device is the z axis.

So, axis x of the accelerometer is in column a axis y of the accelerometer is in column b axis z of the accelerometer is in column c the same holds true for the gyroscope and when kept stationary. So, the axis x of the gyroscope is in column d the axis y of gyroscope is in column e and the axis z of the gyroscope is in column f. So, I go back to the MATLAB code and I read these values into a particular variable. So, from the file I get into a variable which is called data. So, my accel x is the first column as we know. So, we call it from the first column access y is from the second column accelerometer z is the third column. So, we call it respectively the gyroscope data which is in which is the x axis gyroscope data is in column number 4 the gyroscope y data is in column number 5 and the gyroscope z data is in column number 6.

So, this is how we read the data from the csv file after reading the data from the csv file we calculate the mean bias value as Professor vishwanath has already spoken to you got bias we will be calculating the bias of these values that we have in an experiment where we have collected the data. So, we take around 200 samples we calculate the sum of this 200 samples and divided by 200. So, we get the mean bias which is in a stationery condition of the x, y and z axis of the gyroscope this mean gyroscope value has to be subtracted from each of the axis now we consider only the y axis. So, I am subtracting the gyroscope mean value of y into the gyroscope y value.

So, the bias is a basically removed. So, here are some experimental results of the bias where x axis is measured as 0.04, the y axis bias is measured as 2.85 and the z axis bias is measured as 1.029. So, here this is an experimental set up where we have measure these bias which may not be true all the all the time. So, if you want to calculate the bias we have to keep the IMU stationery on the ground and calculate the bias and remove of the bias initially from the gyroscope value.

So, next we would say; what is the data rate at which we are getting the data from the accelerometer the gyroscope. So, the data rate at which we are getting is around 200 samples per second it is in the code where we actually call the data in at this sample rate. So, we get 200 samples per seconds. So, t s which is also delta t is 1 by 200. So, this is the delta where delta t where we need to compute the alpha for the high pass filter and the low pass filters. So, here specifically for the high pass filter.

So, as we know that the sensor is kept stable on stationery on the ground on the table. So, we consider the first value of the angle of the y axis to be 0 and we have a for loop where we integrate the gyroscope y value as we said we consider the y axis you can consider the z axis or the x axis, but here in this case we are considering the y axis. So, we keep the y axis stationery or the IMU completely stationery and we calculate the angle from the y axis. So, ang y is a variable where we get the value of the angle from the gyroscope.

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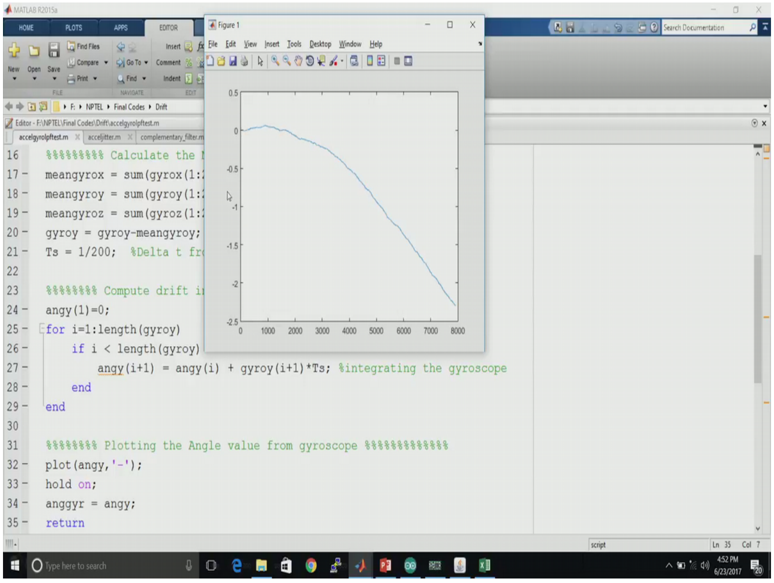

So, if I plot this value of the gyroscope. So, here is the graph of the angle measure by the gyroscope. So, the y axis is measuring the angle the z the x axis is measuring the samples. So, we can say that over a period of time which is around eight thousand samples my value of drift my value of the angle which is when kept stationery has move from 0 to around 2.25. So, we see that there is a lot of drift in this experiment that we conducted. So, how do we remove the drift of the angle computed from the gyroscope is by passing through the high pass filter.

So, I will be telling you how to pass through the high pass filter as we have seen how to calculate the filter coefficient previously in the lectures given by Professor Vishwanath, I will be going through the same again. So, f c is the cutoff frequency where f c is equal to 1 by 2 pi r c. Now we calculate for r c which is your time constant tau is equal to 1 by 2 pi fc from this, we calculate your tau value as a tau is equal to r c and when you want to calculate the filter coefficient alpha hp is equal to tau divided by tau plus delta t or in this case it is it is mentioned as t s.

So, filter coefficient that we have calculated is for 3 hertz your cutoff frequency of this filter is at 3 hertz and we get the alpha value of 0.8641. So, we pass this; this the angle computed from your gyroscope through the high pass filter using this filter coefficient. So, now, that we know that the alpha which for the high pass filter is 0.8641 we put it in the high pass equation which is defined previously which is explained you by Professor Vishwanath.

So, we get the value of the high pass signal as anggyryhp. So, if I have to plot this value of anggyryhp with I would get graph which looks similar to this yeah now you can see that your blue line as seen previously is your angle from your gyroscope which is drifting of even when kept stationary and when we passed through the high pass filter we get a very smooth line which is almost at 0 all the time. So, here is how we correct the drift from the angle of the gyroscope by passing it through the high pass filter.

Now, I will be taking you through how to reduce or how to reduce the jitter from your accelerometer by passing it through the low pass filter.

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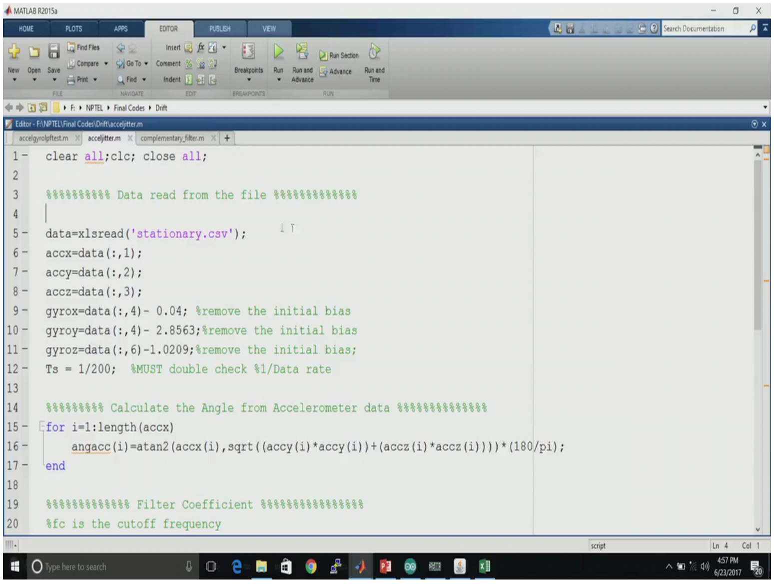

Yeah. So, all these codes are available in your forum if you have any doubts with the codes you can always contact me. So, over here we are getting the data of the same stationary value we know that your accelerometer data is in column number one accelerometer y is in column number 2 accelerometer z is in column number 3 here we do not consider your gyroscope, but for computational I have given the values over here as we note from the previous experiment for the high pass filter t s is your delta t and my sampling rate is around 200 hertz.

So, I get 200 samples per second where delta t is one by 200 this has to be checked properly while your conducting the experiment because every time we will not get standard data rate unless you have defined your data rates well. So, please check this before you use the same code now we calculate the angle from your accelerometer. So, the angle from your accelerometer is calculated using this formula. So, we have already shown to you as how what the formula for the accelerometer angle computation is. So, this is how we implemented in MATLAB.

So, once we have got this data I want to design a low pass filter for this accelerometer data. So, as this as shown before I will go through the cutoff frequencies and how we calculate your filter coefficients from the cutoff frequencies; so, f c is your cutoff frequency where the formula of f c is equal to 1 by 2 pi r c; r c is also your tau which is your time constant which can be said as one by 2 pi f c. So, now, your alpha for a low pass filter is delta t divided by delta t plus tau.

Once we substitutes the values of tau and delta t or ts in the equation we get the value of alpha for the low pass filter again over here the alpha for a cutoff of 3 hertz is around 0.0909. So, we consider this 3 hertz as for the high pass filter we have also consider the 3 hertz as the cutoff frequency we consider the 3 hertz cutoff frequency even for your low pass filter.

So, we pass the angle computed previously from your accelerometer data through the low pass filter. So, this is your equation which is being implemented in MATLAB the equation is previously shown. So, you can implement this equation for a low pass filter in this manner once we pass the accelerometer data through the low pass filter we can see how we remove the jitter from the angle computed from your acceler meter data.

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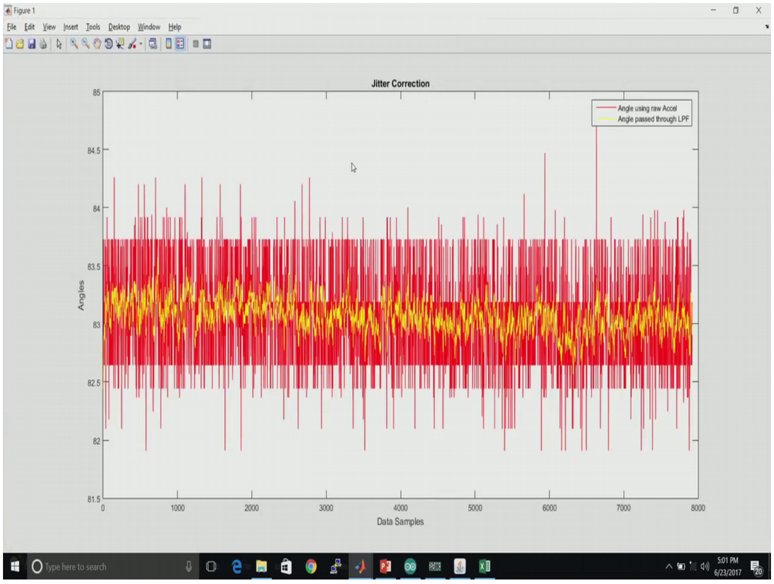

So, here is the graph where one caps stationary the accelerometer not moving. So, we need to get an angle which is ideally a straight line, but as we see, but the angle calculated from your row acceleration value which is in terms of red has a lot of jitter and the angle computed after passing through the high pass the angle computed from your accelerometer after passing through the low pass filter is in yellow. So, we can see there is a considerable amount of jitter which is being removed while pass through the low pass filter.

So, now, I will be showing you on how we combine low pass filter and a high pass filter to get the complimentary filter now I will be showing you how the complimentary filter block is design where we combined the angle calculated from the gyroscope and the angle calculated from the accelerometer in the previous experiments I have shown over here the basic steps are very similar. So, we have the data we read from the stationary file and then we assigned to variables which are a accx accelerometer x, first column accelerometer y the second column accelerometer z which is the third column the fourth is the gyroscope x fifth is the gyroscope y and sixth is the gyroscope z.

So, we find the mean which is the bias and we remove the bias in this way and we know that the t s which is the delta t is one by 200. So, now, we need to calculate the angles from each of the data it each with after sensor which is the accelerometer and is gyroscope. So, we found out we keep the initial condition from the accelerometer which is this formula atan 2 accel x divided by square root of y square plus z square and the gyroscope is also initially given the same angle which is accel x divided by root of tan inverse of accel x divided by square root of y square plus z square.

So, now, here we calculate the angle from the gyroscope in this way and we calculate the angle from the accelerometer in this way now we have the complimentary filter which is a ca a combination of your low pass filter with the high pa with your high pass filter using a particular filter coefficients here we know that we have a stationary position. So, we need to trust the accelerometer more than the gyroscope because the gyroscope has drift. So, we choose our filter coefficients of are a complimentary filter in this manner where we choose 1 minus alpha is equal to 9.98 and alpha is equal to 0.02. So, now, we can plot this signal.

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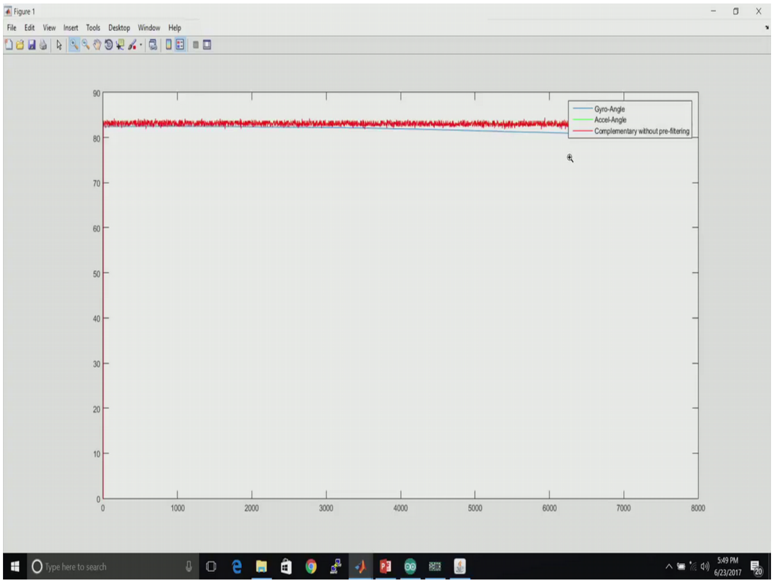

So, we get it in this manner as we have seen previously the blue line is the angle computer from your gyroscope and the green line which is super imposed by the red line over here is your angle computed from your accelerometer and the red line is the actual complementary filter angle.

Now, this is them without filtering without passing each of the angles through the high pass filter or the low pass filter. So, let us see on how the dynamic change when we pass the angles calculated from the gyroscope and the accelerometer through the high pass and the low pass filters as previously calculated are filter coefficients for the low pass filter.

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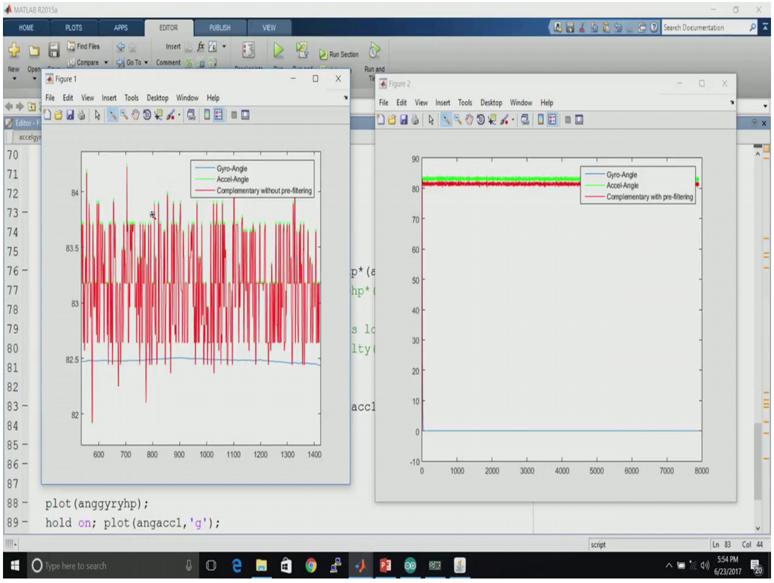

And the high pass filter is are follows the alpha for the high pass filter is previously calculated us point a 0.8641 and for the low pass is 0.0909 we have seen that in the previous experiment as to how to calculate the alpha values the initialize the values which are required for the computation of these angels.

Now, we compute the angles of the accelerometer using this formula after computing the angle we pass these this angle which is angaccel one inth into your low pass filter where your accelerometer data of the x y and the z is passed through the low pass filter next we compute the gyroscope angle in this way. So, the gyro angyro is added with the gyroscope y value and multiplied with delta t where the numerical integration is the gyroscope into delta t which gives you angular position.

So, we pass this gyroscope value through the high pass filter the high pass filter of the gyroscope the angle calculated from the gyroscope is this equation. So, the equation is already previously mentioned where we pass the angle from the gyroscope through the high pass filter, now we see that this 2 have to be combined using the complimentary filter. So, the filter coefficients from your complimentary filter is alpha is equal to 0.02 and the 1 minus alpha c f is equal to 0.98.

So, now, we can see the difference in the graphs that we get with pre filtering and without pre filtering from the high pass and the low pass filters yeah on the left side we see a plot which is the angle calculated from your gyro which is the blue graph the angle calculated from your accelerometer is super imposed by your complimentary filter which is the red graph, but the green graph is your angle computed from your accelerometer the red graph over here is the complimentary filter angle.

So, here we do not pass the angle from your gyroscope or the angle from your accelerometer through the high pass or the low pass filter is respectively we just pass it we just combine these 2 angles directly I have to get the complimentary filter and the right side we have the angle from your accelerometer which is in green the angle from your gyroscope which is in blue. And the angle from your complimentary filter which is in red again here we pass the angle computed from your gyroscope and your accelerometer through the high pass and the low pass filter and we combined these 2 to get this complimentary filter value I will tell you why the gyroscope value is towards 0 that is because we see over here that the gyroscope is basically stationary.

So, now the moment or what the angular velocity which is present in the gyroscope is very low. So, we pass it when we compute the angle; it is basically a stationary angle with lower frequency dynamics as we see that the angles computed from the gyroscope when pass through the high pass filter the lower frequency which is below the cut off frequency is actually filter out an attenuated hence we get the value which is close to 0 because all the frequencies which are present in stationary is actually attenuated by the high pass filter and we get a 0 angle. So, now, we can see that in a stationary condition where the sensor is not moving we can trust the accelerometer more than the gyroscope.

So, now, we have go we have seen the complimentary filter where we combine the angles ca computed from the accelerometer and the gyroscope which is pass through the low pass filter and the high pass filter respectively in a stationary position now I will show you an experiment where we have actually taken the gyroscope which is strapped on to the hand and we move the act the gyroscope and the accelerometer which is sensor which is over here in 0 to ninety degrees manner and bring it back to 0 degree. So, it goes from 0 degrees to 90 degrees and back all the way to 0 degrees. So, here is a file where which is called moment out 0 I will not run through that code because it is a same code I will just show you the graphs.

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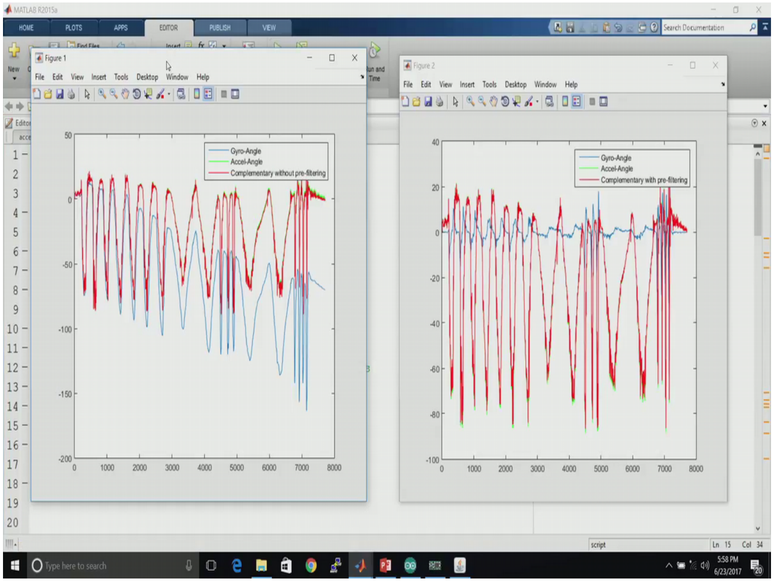

So, the graph on the left which is your figure one is where we find the angle from your accelerometer and the angle from your gyroscope without passing through the high pass and the low pass filter and combining these 2 angles together in a complimentary filter. So, here we can see that the blue line is the angle computed from your gyroscope the green line again which is super imposed by the red line is your accelerometer angle and you see that the red line is your complimentary filter angle here we can see the value of drift your we can see that though the angle computed from your gyroscope is drifting in a way where we get peaks from 0 to around 60 degrees, but at sample number seven thousand we actually start the angle value from 60 degrees to around hundred and twenty degrees.

So, here we can see the gradient in which there is the drift. So, now, again on the right side we have the angle computed from your gyroscope which is the blue line the angle computed from your accel which is your green line and the angle computed from your complimentary filter which the red line here we can see that. So, once we compute the angles and pass it through the high pass and the low pass filter respectively or we get this kind of a response from the complimentary filter which is your red axis after computing the angles we see that we are trusting the accelerometer more than the gyroscope, but we can we can play around with the alpha value of the complimentary filter to trust either the accelerometer or the gyroscope you would trust the gyroscope more in past dynamic moment.

. So, an example to show you how we can trust the gyroscope more on the left side we can see that till sample number 3000, we have a slow speed motion where we do not move very rapidly we have value where we compute in a very slow manner on the right half where we start from around 6500 to 8000, we have past dynamics. So, here if I zoom in to the plot you can say that the frequencies above 3 hertz also are captured from what is compared previously there are the dynamics of the past motions which are also captured. So, here we can actually compute the complimentary filter by trusting the gyroscope more.

So, now that we see the higher dynamics on and for after gyroscope where the gyroscope can be trusted more I requested you to play around with the alpha of the complimentary filter where if you trust the gyroscope more where the alpha c f is given a higher weightage towards the gyroscope the complimentary filter will actually follow the gyroscope. So, I request you to please try by changing the alpha for the complimentary filter if you have any doubts you can contact me on the forum all these codes are posted over that you can get in touch with me.

Thank you, all the best.