Biomechanics
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Lecture – 75
Measurement of orientation in 3D space - Devices

Vanakam. Welcome to this video on biomechanics. In this week we get started with a new topic which is a practical application an example is how to measure individual segment kinematics you know in the human body.

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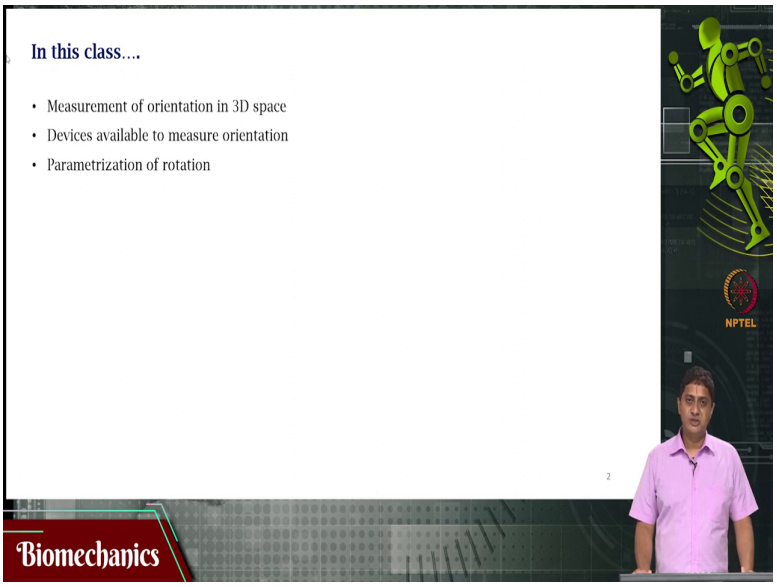

So, in this video we will be looking at a measurement of orientation in 3D space. Devices that are available to measure orientation and how to measure record and compare the information from these and what kind of measurement techniques are suitable for what kind of situations experimental situations right how to parameterize the rotation.

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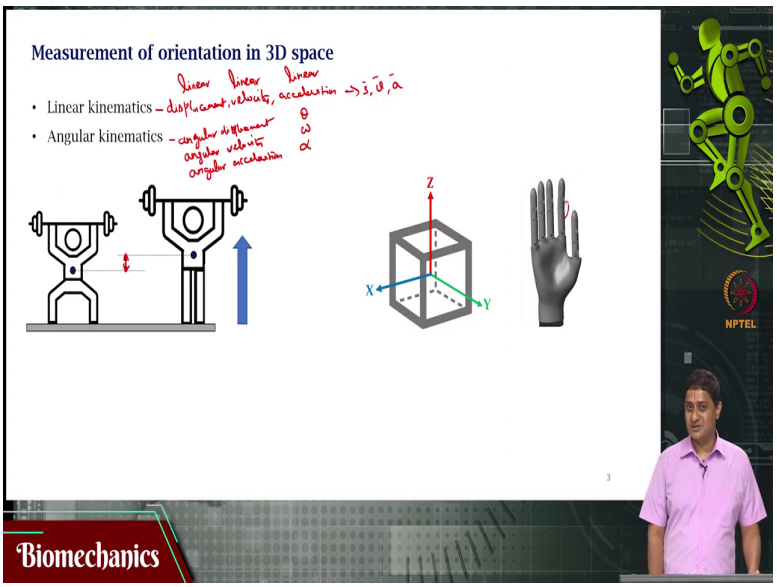

So, when we measure kinematics we are generally interested in when you say generally kinematic you are speaking about linear kinematics that is displacements, velocity, acceleration that is linear displacement, linear velocity, linear acceleration. Then in angular kinematics you are interested in angular displacement, angular velocity, angular acceleration that is notation for these s, v and a that vectors s, v, a.

Angular displacements are Theta, Omega, Alpha remember from our knowledge of high school physics and basic mechanics I know that angular displacement is generally noted as Theta angular velocity is Omega angular acceleration is Alpha. And in general linear displacement is s linear velocity is v and linear acceleration is a vectors these are also vectors by the way the angular kinematics those are also vectors.

Now in this course and in this video we restrict our attention to angular kinematics and not linear kinematics, why we will see in just a little bit. Because our interest in this case and as part of this course is to measure the joint angles or relative body positions joint angles between joints angle between two bones or rigid bodies is what we are interested. So, we are mostly interested in angular kinematics in this course.

And so, we will be discussing that will be focusing a lot more on that when compared with so, for example when this person is lifting from say from this point to that point. So, what is happening is essentially a linear displacement for most practical purposes. But the body itself you know might undergo changes that that might be in angular domain. Actually how this

changes in joint angle get converted to the linear space is a question is an advanced topic that perhaps we will not be in a position to address in this course.

Something for you to think about how joint rotations I will leave this as an exercise if possible you can try this. How rotations that happen about individual joints get converted to linear motion in the Cartesian space that in the in the real world how is that happening. Think about that. We will we will not discuss that as part of the course. For example we are interested in rotations about various axes.

For example here we have a 3D coordinate system that is rotating we are interested in these joint displacements this angular displacements velocities and accelerations and so on and so forth. Take the case of the human hand and fingers it is an example I keep giving the human hand and fingers because it is a very dexterous system but that is not the only reason also because I work extensively in the field of hand finger mechanics.

So, this is my bread butter water this is what I do for a living. So, obviously the examples that I will give will come from this page but that is not the only reason. The reason is also that it is a system that is having a large number of degrees of freedom that many examples can be given just with this one single system that is the other reason. Here what is shown is the movement in a proximal interphalangeal joint right some angular excursion that is happening at the PIP joint proximal interphalangeal joint.

Note that these joints are modelled as hinges they have only one degree of freedom. And so, the movement is going to be restricted to that and the amount of excursion that happen are also restricted by the anatomy and the muscles that are powering this. So, the range of motion is also defined by that.

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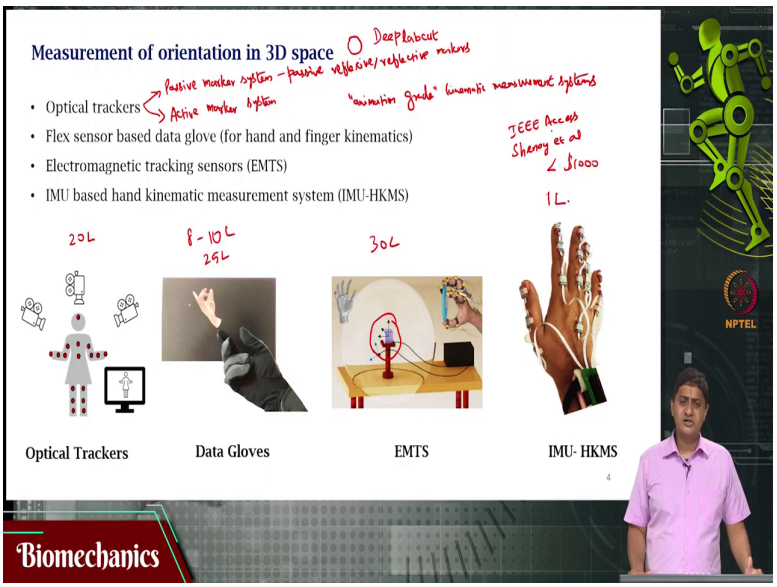

Now we will spend some time discussing how we can measure orientation in 3D space. So, we are interested in measuring orientation of a body of a rigid body in 3D what are the various ways in which you can do it which method is a good which method is better which method is best actually that is no single method that comes across as best in all the situations. So, your choice of the method of measurement depends a lot on the specific situation or the application.

And how much money you can afford to spend there are many things that come into the picture. One gold standard method of measuring joint angles orientation is by using optical trackers. Before we get started with our discussion on optical trackers I thought I will spend a few minutes discussing how you can measure body orientation using a regular web camera you know because these kinds of things this kind of videos or posts you will see on social media.

Where people say that they were able to track hand finger motion or some body part motion using a web camera and a high quality algorithm how are they able to do it. Well there are; so, what they do is they use a regular web camera and they will use some standard markers for example they might put up a small dot say one centimeter in diameter something like that white in colour.

And they will train a network to track this dot that is placed on the body part. They will have a high quality processing system and. So, they will have an algorithm that uses because the computational techniques to process this kind of information to process video or well

developed and the hardware that is available to process video are now well developed they will have a high quality algorithm that is running in high quality hardware system that will track this particular marker.

So, to speak this marker is not a real marker they will just place a small for example a one centimeter circle circular paper a sheet of paper that is just that is just put on the person's body part of interest using say double sided tape or glue or something like that. And that is then tracked using this algorithm and usually these tracking systems are almost real time. So, that means that they must be of really high quality they must be very deep they must have done quite a bit of analysis to arrive at this.

So, these kind of methods are now becoming more and more popular also there are these standard codes such as this deep lab cut for example that are used in estimating the pose from regular video remember these kind of techniques rely more on software relay more on code and Hardware to run this code. So, the particular data capturing system itself might not be an expensive system. So, there are these kind of techniques that are coming up.

However in biomechanics we are interested in not just getting a general sense of the posture we are also interested in getting this data at a relatively high level of accuracy. So, we will focus on the standard research based techniques in the next few minutes but I just wanted to introduce that there are these kind of webcam based techniques that are becoming available those of you who are interested.

Please explore this using just Google is your friend just check deep lab cuts what are the methods that are available to track posture using webcam there are techniques that are available of course that does expect you to be good as a coder you need to be good with python for example. So, there are there are some expectations but these are possible these are now becoming possible this was not possible when I was a student this was not possible 10 years ago this is now possible.

There are a lot of these techniques that are now being developed. Now becoming possible you will have to edit the code according to your needs. So, that requires you to have not just coding capability but also the ability to read good code and debug it according to your needs

that is a special skill will not continue the discussion further we will continue our discussion on optical trackers.

So, optical trackers these are systems that use cameras to track posture of specific body parts or rigid bodies these come in two flavours either passive marker system or the regular camera based measurement system or active marker system. What is the difference well the difference is that passive markers the system is passive active marker of the system is active well you will have to define a little bit more than that right.

So, in the passive marker system light is incident upon the markers that are placed on the body parts the markers themselves just reflect the light that is incident on them. So, something to keep in mind that these are passive reflexive markers reflexive or reflective however you say it whichever is the correct English word or technical word check that these are passive reflexive markers.

So, that means that they do not have energy consumption by themselves. So, these markers are placed on specific body segments and light is incident on them and these markers reflect the light that is incident on them the cameras capture the reflected light. And then they there is a calibration routine and a calibration method and then a rigid body model of the measured body part is then being generated which then is used to you know reflect these moments hopefully in real time or at least for analysis.

There are advantages and disadvantages to this system which I will discuss in just one minute. Active marker systems are those in which the markers generate light at a given wavelength this may be by the way in both these systems the light may be regular visible light or IR light. So, active marker systems generate light at a given wavelength. So, each of the marker has a specific signature wavelength.

So, if you tell the software the managing software that is going to collect this data where you are placing a given marker the marker has a code number and that code number is placed say for example in the upper arm and. So, the software is expecting light of a given wavelength from that marker and whenever light of that wavelength is received it knows that that it is coming from the upper arm another marker that is placed in the forearm.

For example will send this light at a different wavelength and the system knows what is that wavelength to and likewise for all these body parts? So, it knows based on what is the wavelength of the light that is measured it knows there from where it is coming and. So, generation of this model is a relatively simple process not just that sometimes what happens let us say that I have a set of passive reflexive markers that are placed on my two arms both these arms.

And I am doing that you are watching me where the camera that is measuring this movement is placed where this visible light camera that is measuring our recording is placed at around the same place and I am doing that for example. Now what will happen is that the markers that are the passive reflexive markers will cross over each other right. For example when I am doing that kind of a moment there will be crossing over of this passive reflexive markers sometimes some of the markers will not be visible.

So, there might be tracking problems. Nowadays software is available to automatically track the markers sometimes nowadays relatively rarely in the good old days 15 years ago tracking this was a manual process involved quite a bit of manual process. Now more and more the software's are becoming more and more smart that they are able to do this tracking in a much better way that the amount of manual intervention that is required is minimized.

But it still is involving some amount of manual intervention for example when I do this it is not clear where which marker is because the marker on the palm of the left hand and the marker on the palm of the right hand will cross over and you do not know which palm is going where that for a there will be a little bit of a confusion usually this should not be that. But it could happen; so there will be tracking. So, there will be tracking problem.

So, the disadvantage of the passive reflexive marker system is that that may be tracking errors a tracking problem or there might be a need for manual tracking in the passive reflexive marker system. If I use the active marker system this problem will not be there why because the marker on the on the right hand and on the left hand will use different wavelengths. So, when they move there is no confusion to the camera which hand is moving in which directions.

Because these slides have different wavelengths or this light this these two markers send out light at two different wavelengths. So, it there is no confusion and. So, tracking is relatively easier extremely easy. So, there is no need for manual intervention but is it that this system has no disadvantage there is the disadvantage that active marker systems are active. That is they require energy if you have to generate light and transmit it.

You will need to spend some energy that has to come from a battery it can have a central battery from which all these markers are powered that means that that Central battery will have to be connected to all the markers via a cable. Whenever a cable is involved it is possible that that cable might restrict movement there are many constraints that come into this or the other idea could be that I can have individual markers that come with their own battery.

In this case there will be no cables but the disadvantage is that each of the marker will be bulky that it cannot be put on small parts of the body such as fingers there are many challenges. So, challenges are there both for passive reflexive markers and for active markers you will have to make the choice as to which one do you want. In general optical tracking is considered gold standard when it comes to measuring kinematics that is no second thoughts about that.

There is no second there is there are no challenges there are no questions about that in nowadays technology is available to provide this feedback in real time also. So, there is quite a bit of advancement in this field in general optical tracking systems are considered the gold standard. And they are also somewhat expensive there are some systems for example Optitrack type of systems that are relatively inexpensive but they have their own limitations as well.

So, you cannot have the cake and eat it too but there are no relatively inexpensive systems or what are called as animation grade kinematics measurement system. I do not want to endorse or suggest names of companies there are some animation grade kinematic measurement systems that are available in the market remember these are animation grade that means that they are not exactly research grade.

But they can be used in research with a little bit of modification with a little bit of challenge they can be used to measure data for research also, so, much about Optical tracking. If you are interested in hand kinematics like I am interested mostly I am interested in hand kinematics more than whole body kind of medicine the rest of the body kinematics I am interested in hand kinematics.

If you are interested in hand kinematics one option is using flex sensor based data cloud or some sort of data cloud that uses resistive Bend technology there are some standard companies that are available that generate this that that manufacture these kind of gloves for hand and finger kinematics. The advantage is that there is no worry of line of sight. So, Optical tracking systems also have this problem that at all times during the measurement each of the tracker each of the marker must be seen by the camera.

So, that is a need for the camera and the marker to have line of sight there should be no occlusion or obstruction between them. That problem is not there when you are using a glove to measure kinematics of the hand and fingers. So, this we get rid of this line of sight problem let us briefly discuss this data glow technology. What this does is it uses resistive Bend sensors the idea is that depending on the bend amount of Bend in the sensor the resistance of that sensor will change.

So, the output voltage will change accordingly it turns out that over a relatively large range the relationship between the amount of Bend and the output voltage is linear and it is possible to calibrate this the challenge is calibration you need to have this calibrated for each hand that you are using you cannot assume one calibration or calibration used for one person to be true for another person usually it will not work.

So, that means that each hand requires its own calibration it might appear as if calibration works but sometimes only when you perform relatively complicated manoeuvres such as that one where the tip of the little finger and the tip of the thumb touch each other right those are those are kinematic manoeuvres that involve this Palm Arch right. This kind of manoeuvres usually cannot be easily captured by this kind of system there are many challenges with this.

There are challenges with this and you need to have them properly calibrated not just that the accuracy of these systems are relatively limited. So, the accuracy is usually you know you get

what you pay for there are systems that come for even few thousands of dollars the accuracy is not that great. So, it really depends on whether you are interested in studying the mechanics at a detailed level where you are carrying about the accuracies where you are carrying about one degree here and there.

Or let us say that you do not care that much about that but rather you are worried about general changes not in patterns of movements such as coordination patterns such as learning those are more like you are interested in how the control or coordination pattern changes over a period of time or over a task for example. In those kind of things maybe you are not looking at that kind of accuracy again.

I am not saying this is good or bad I am just saying that these are available. So, there are some challenges with this these are relatively inexpensive systems the advantage is that line of sight problem is not there another advantage is that they are inexpensive the disadvantages are you compromise on accuracy and they need calibration for each hand. So, that is the other the other idea is to use electromagnetic tracking systems.

Those that use electromagnetic trackers the idea is that there will be one transmitter like the one that is shown here this is our lab setup. This is a lab this is the equipment that we use in our lab this is exactly the arrangement that we use in our lab the neuro mechanics laboratory mattress. So, where we keep the transmitter at one point it sends out and a magnetic field. So, moment of a given tracker within that magnetic field it turns out is relatively linear over a large range.

So, I can measure these movements depending on the depending on the field right. So, that I am measuring. So, this can be calibrated relatively easily the challenge is the the advantage is the line of sight problem is not there the challenge is that these are expensive. It is an expensive system these are extraordinarily accurate they are very very accurate. They are expensive but there is a bigger challenge that instrumenting these on small parts of the body like the hand can be very tedious can be tedious.

And also many of this most of these sensors are delicate they need to be handled like babies. So, unless you are working with slow movements these may not work well because if they are very fast there is a possibility that the cable might snap which will essentially cause

damage of this equipment. So, there are there are some challenges with this kind of equipment also they are expensive they are accurate but they are expensive.

And they are also fragile are very delicate they need to be handled carefully and preferably they must be used only for movements that are relatively smooth and not very fast not high velocity. Sometimes when you are using fingers and when people are making that kind of very fast moments it is likely that there might be a snapping of the cable and the coil that is used for the measurement.

This permanently damages the sensor and is not covered by warranty. So, the manufacturer will not replace this for you. So, there are there are some challenges and difficulties with this kind of measurement system. Then something that we have developed in our lab a variant that we have developed in our lab is an inertial motion unit based IMU inertial motion unit based and kinematic measurement system that we have developed in our lab.

While we are discussing this let us discuss have a sense of the costs right. So, if you are talking about Optical sensors for whole body measurement you are speaking anywhere between well even if you go for the inexpensive animation grade like after track you are easily for whole body measurement you are easily looking at around 20 lakh rupees. Data gloves depending on the cost anywhere between anywhere between five but accuracy is less remember.

For one pair of glows anywhere between 8 to 10 lakhs I guess about 8 to 10 lakhs one has to really check for this there are many ranges that are available. The best ones come at about 25 lakhs right. The electromagnetic tracking system the gold standard ones easily going to set you off by about 30 to 35 lakhs for the 16 segments for the 16 sensor system that are that is required for hand kinematic measurement.

This one we have made in our lab the manufacturing cost not the cost at which we are selling this the manufacturing cost comes to about 1 to 1.25 lakhs. So, what but of course you will say that hey but you are not going to get the accuracy that you are going to get with the optical system of course not we are not saying that we will get that kind of accuracy but we are getting some relatively good accuracy.

So, our costs our accuracy is sub 4 degree angular accuracy and the cost that you are paying is like you know about thousand five hundred dollars thousand two fifty thousand three hundred dollars I think I think I think we have made quite a bit of progress with this and we are continuing to improve this. We are continuing to improve this we hope that we will be in a position to sell this whole system for less than well when we sell our manufacture this whole system for less than one thousand dollars for one hand.

We have published a couple of papers on how we made this we are still continuing to improve this and we are filing a patent on this technology in the next few months. We have a couple of papers on this topic please check my website there are a couple of papers in IEEE, Access both of these papers start with Chennai here is your teaching assistant for the current semester.

The first offering prajwal Chennai is your teaching assistant he is the first author in both of these papers to check these papers where we have given all the details. Now I am not going to spend the time spelling out how we made this how we made the choice how we made the board how we made the connection with the microcontroller all those details are available in my papers I request you to please take the time and read.

Because if I start describing that then that will become the main focus of this video. So, we will stop here we will continue our discussion in the next video. So, in this video we looked at linear kinematics angular kinematics and various ways to record measure kinematics and we had a discussion on essentially a comparison between various types of technology that is available to measure.

And the take home message is that you know it all depends on what you want cost is a constraint the accuracy that you want is a constraint the specific requirement in terms of whether you know line of sight is needed or not line of sight occlusion may happen or not in your task is a constraint. All these things play a role in your decision to go for which measurement system. So, we will stop here we will continue our discussion in future video. Thank you very much for your attention.