Exercise & Sports Biomechanics
Dr. Rajinikumar Palaniyappan
Centre of Excellence in Biomechanics Cum High Performance Centre for Sports
Department of Sport Biomechanics & Kinesiology
Tamil Nadu Physical Education & Sports University, Chennai (TN)
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Lecture 37
Introduction to Optical Imaging Systems

[Today we are going to learn about the introduction to optical imaging systems.

First, we will see what a motion capture system is].

What is a motion capture system?

The motion capture system is shortly called MO-CAP. Let us see the different types of motion capture systems.

First is the optical motion capture system, where markers are used. Markers are placed on the athlete's body, and the IR infrared cameras are used to track the markers' movement in 3D space. After capturing the markers' movement in 3D space, it is analyzed and quantified. In this, we have the QUALISYS motion capture system. The QUALISYS product comes with an IR camera and software for capturing the markers in 3D space. Then comes the **VICON motion capture system**, and the third one is the **OptiTrack motion capture system**.

To simply explain, in a **marker-based motion capture system**, we use infrared cameras, markers, and a computer to capture the movement with specified software. The second component is called a **markerless motion capture system**. So, in the laboratory, we can use a marker-based motion capture system. But in outdoors, the athlete will move in different spaces, and it is quite complex for the researchers to assess any athlete with markers. So, for easy assessment and easy capturing of movement, markerless system is being used by the researchers and movement science professionals.

In markerless motion capture system, we use video camera and a dedicated software. **SIMI motion analysis** is one of the markerless motion capture system where the cameras and dedicated software is used to capture and analyze the athlete's movement in sports environment. Second comes the Theia.

Theia is one of the markerless motion capture software and the third one is the **Contemplas**.

The **Contemplas motion capture system** is also one of the markerless motion capture system. So, here we have seen both marker based and markerless motion capture system, where the optical imaging that means the camera is used. But without camera can we assess any athletes movement and can the athletes move without any difficulty and at the same time can we capture the movement of the athlete?

The answer is yes, the advanced system is inertial measurement units that is inertial sensors. So, these inertial sensors do not need any camera but these sensors can be wrapped around the athlete's body and the athletes can be captured and assessed in the sports environment without any complexity. And XSENS is one of the IMU sensors where it provides the solution to quantify the athlete's movement in the sports environment.

The second one is **Delsys**. Though it is an EMG sensor company, it also comes with built-in IMU sensors where the athlete's temporospatial parameters are measured. The moment we talk about IMU sensors, they come with an accelerometer, gyroscope, and magnetometer. So, these are the basic sensors built into IMU sensors. And the third one is **Vicon**.

Though **Vicon** is a motion capture system, it also comes with IMU sensors. And these are all the different technologies being used in the industry to quantify athletes' movements in the sports environment. You can easily see the athlete's body with markers in the marker-based motion capture system, and the markers are being tracked and quantified in 3D space. At the same time, if you see the other side, the athlete can do any free movement and no markers are placed in the markerless motion capture system.

Next, we are going to discuss the **infrared cameras**. Shortly, it is called an IR camera. The IR cameras are used to track the markers in 3D space for further analysis. And in this picture, if you see, there are so many cameras which are tracking the object in the three-dimensional space. So, the three-dimensional space means X, Y, Z space.

Furthermore, we will see the **different types of cameras**, particularly the products available in the industry of motion capture system in sports. First one is the **Qualysis motion capture system**.

In Qualysis motion capture system, there are IR cameras that is infrared cameras, as well as video cameras available. So, in infrared cameras itself, there are different types of cameras available. And these cameras are specifically used for different sports application. Whenever we use any camera or optical motion capture system, first thing is its FPS, frame rate. Second one is its **resolution** and the third one is its **field of view**.

Based on these fundamental three components, the cameras have been classified here as A26, A12, A9 and A5. So, the A26 or Arqus 26 camera comes with more resolution and less frame rate whereas the Arqus 12 comes with a moderate resolution and a very good frame rate and the resolution is less compared to the previous two in A9 but the frame rate is high. As a principle, when the resolution is reduced, obviously the frame rate can be increased. Here, out of these four cameras, you can see a camera with good resolution and optimal frame rate that is easily, that can be identified, that is A12.

Then, you can see the different cameras of QUALYSIS motion capture system. So, A5, A9, A12, A26, these four are different IR, that means infrared cameras, and M1, M3, M5 are video cameras. First one is FOV, in full field of view, you can find the resolution as well as the frame rate and resolution. What is the resolution and frame rate when the camera is functioning under high speed mode? And third one is its resolution.

So, the IR cameras comes with the resolution, the frame rate and field of view. At the same time, you can also see the video cameras. The video cameras, the moment the resolution is reduced, the frame rate increases. So, we select the cameras depending upon our nature of movement capture. And further, you can see here the maximum capture distance of the camera. So, A5 captures from 26 meters and 28 meters is A9 distance. And A12 captures the farthest distance of any marker that is 40 meters and A26 is 32 meters. And you can see the distance where the video cameras can capture an object. So, M1 with 10 meters, M3 with 15 meters and M5 with 18 meters.

Other than QUALYSIS motion capture system, there is **another product called the Vicon motion capture system**. The Vicon motion capture system has **two types of IR cameras**. One is **Valkyrie**, and the other is **Vero**.

Valkyrie comes with three models: VK8, VK16, and VK26. The number denotes the resolution of the camera, which is 8 megapixels, 16 megapixels, and 26 megapixels.

The third component, or the third motion capture system used in the industry, is the **OptiTrack motion capture system**. The OptiTrack cameras can be seen in this picture, and these cameras are used in marker-based motion capture systems. We have seen all three types of marker-based motion capture systems, and now we are going to see the IMU sensors. These IMU sensors are used without any camera because they do not need one. The sensor has to be wrapped around the body to capture kinematic data.

In the IMU sensor unit, we predominantly have three sensors. One is an accelerometer, a gyroscope, and a magnetometer.

What is an accelerometer?

An accelerometer measures acceleration, a gyroscope measures angular velocity, and a magnetometer measures direction and position.

And you can see the range, frequency of the sensors, and axis of the sensors, as well as the sensitivity. And we have seen both marker-based systems as well as markerless motion capture systems. Fine. But there are cameras or systems that are hybrid in nature. These cameras can be used to track both marker-based motion capture as well as markerless motion capture.

Which motion capture system is better - a marker-based motion capture system or a markerless motion capture system?

The marker-based motion capture system is always more accurate than the markerless one because the precision is higher. The marker-based motion capture system achieves less than 1 millimeter accuracy.

[Now, we are going to see the importance of the optical imaging system].

What is the purpose of the optical imaging system?

The optical imaging system provides us with detailed real-time data on the sportsman's movements, which helps enhance the performance of athletes and reduces the chances of

injury in sports. Further, the research community uses this motion capture system for future applications. The applications in sports biomechanics and sports science can be seen in the further course of slides.

Why do we use the optical motion capture system?

First, we capture the fundamental movements, namely walking and running gait analysis, and in this analysis, we measure and quantify the joint kinematics. The joint angle, joint angular velocity, and joint angular acceleration parameters are measured in an optical motion capture system. We also optimize this technique for any sport. For example, if it is the long jump, we use the hitch-kick style or hang style after takeoff to clear the distance horizontally, and the technique can be optimized using an optical motion capture system.

When it comes to equipment design and optimization, whether it is a tennis racket, a badminton racket, a cricket bat, or a hockey stick. This equipment can be designed based on data from the optical motion capture system. The motion capture system is used in the optimization of sports techniques. So, when it comes to the optimization of sports techniques, the long jump takeoff—athletes after takeoff use either the hang style or hitch-kick style.

The same is the case when it comes to javelin throw or any skill. So, any skill or technique can be optimized only through the optical motion capture system. Further, when we design any equipment, whether it is a cricket bat, tennis racket, badminton racket, or hockey stick, the equipments are optimally designed using an optical motion capture system.

Next, the major industry that uses the optical motion system is the ergonomics industry, and the optical motion system is used for sports performance metrics and analysis. So, these are all the areas where the optical motion system is used in biomechanics as well as in sports science.

Next, we will discuss how to choose the right **Qualisys camera**.

When you go outdoors in different weather conditions, whether it is rain, snow, or dust, and when the temperature ranges from minus 15 degrees Celsius to plus 42 degrees Celsius. If you need industrial-grade cabling, then you should go with Arqus Protected. So, Arqus Protected is a camera with standard housing and an IP67 feature.

Next comes **the camera**, which can be used for long-distance tracking. And if you want to measure at high frame rates, then you should select Arqus Standard.

If you want to use more cameras, and if the budget is very small or if you have a limited budget, then you should go for Miqus video cameras for the optical motion capture system. So, we are discussing in detail about a **Qualisys Arqus camera** since we have the facility with Qualisys cameras. Since we do not have Vicon or OptiTrack, we will discuss in detail with examples **how the Arqus cameras are portable and what the working model of these cameras is**. And if you see here, the daisy-chained cameras are visible in the first picture.

What is daisy-chained?

In rest of the motion capture system, you have to use more number of cables whereas in QUALYSIS, you can use only a minimal cable which will reduce almost 80% of the cabling because one camera supplies the power as well as transfers the data to the other camera. A single cable can be connected with each camera And the final end cable can be connected to the computer. When it comes to motion capture system, we need cameras and the markers and then the good computer and then the capturing software.

So these are the more main core components which is needed. Further, we need a calibration kit. to calibrate the area of capture or volume of capture. And here, these Arqus cameras are functioning under Daisy-chain. And then, the aqcus cameras can be easily fixed and released on a Manfrotto tripod.

Then, the cameras are coming with the Pelican cases where the cameras can be easily carried to different place in a safety way. And in the bottom you can see the calibration wand and calibration case. Further, we are going to see about the video camera specifications. You can see the different video cameras enlisted and its resolution, and then the frame rate in marker mode and frame rate in full HD video mode. When the resolution is reduced, you can see the number—I mean, the frame rate increases from 120 to 480 in the Miqus Video Plus camera. And the field of view can be seen as 51 degrees by 40 degrees. And the Miqus Hybrid comes with 61 degrees multiplied by 37 degrees. And the Miqus 3 comes with 64 degrees by 41 degrees. And this optical motion capture system captures the kinematic data of the athletes in 3D space.

But To get more information or insight, the optical motion system—or optical motion capture system—can be integrated with other hardware, namely the EMG, the force plate, the instrumented treadmill, and the eye tracker as well as eye views. So, the optical motion capture system facilitates the integration of other hardware to get a complete solution to a problem where the athlete will receive a valid, reliable, and objective remedy. The optical motion system captures all the movements and is integrated with other hardware. The optical motion system software acts as the principal software to integrate the other hardware. Let us see the working principles of IR cameras. The infrared cameras always track the markers. The markers are spherical in nature, and in a 3D motion capture system, any one marker must be seen by at least two cameras. And for optical movement capture using an optical motion capture system, we need a minimum of eight cameras.

The aid camera system is used to avoid marker occlusion. If any marker is hidden, it can be tracked by the other cameras to facilitate motion capture for further analysis. And the IR cameras always emit infrared lights that are reflected by the markers. You can see in this picture camera 1, 2, and 3. Each camera shows a corresponding image where the portion of the marker is given in two dimensions.

[We are going to see the types of markers in the motion capture system].

There are two types of markers used in optical motion capture systems.

One is passive markers, and the other is active markers. First, we will see what passive markers are.

The passive markers reflect the light emitted by the camera. Because the camera emits light on the markers, the markers reflect the light. And the reflected markers are captured by the cameras. And you can see the markers before the infrared cameras flash. The markers are placed on the athlete's body, so you cannot see any reflection.

But the moment the motion capture starts, the cameras automatically emit light, and the light is reflected on the markers, which are fixed on the athlete's body. You can see the markers with brightness after the infrared cameras flash. This is how the passive markers are tracked by the IR cameras for motion capturing. We use markers that are spherical in nature. But when it comes to gadgets or equipment used by athletes, particularly balls, we use retroreflective sheets on the balls to track their trajectory and movement in 3D space.

[Next, we have active markers].

Active markers, or LED markers, are placed on the subject and come with a wired connection or an onboard battery, as the active markers emit light. Here, we see different sizes of markers. The spherical markers come in different sizes. There are seven sizes typically used in motion capture systems.

From the small marker size of 6.5 mm, then 8 mm, 9.5 mm, and 12.5 mm. So, from 6.5 mm to 12.5 mm, we use them for small objects or small segment movements in 3D space. But for sports applications with large or fast movements, we use 14 mm, 16 mm, or 19 mm markers. We comfortably use 16 mm markers to track any object or athlete's movements in a 3D environment using IR cameras and 60 mm markers.

Now, we are going to see how a marker-based tracking system is working. So, here you see in this picture the cameras, the subject or the athlete and the computer along with the software. So, first we fix the markers on the athlete's body. Then the infrared cameras are fixed in the ideal place so as to capture the calibrated volume and then

The markers are labeled after the capturing and then the software filters and does the manual corrections to improve the accuracy of the data. So, this is how the infrared motion capture system workflow is followed.

Motion capture system under markerless category:

The markerless motion capture system uses artificial intelligence and computer vision to detect the body movements. Here you can see in this picture the athletes can do the natural movement where the markers are not fixed on their body.

The artificial intelligence as well as the computer vision helps to create the 3D coordinates on the body. So in this markerless motion capture system, On the right side, you can see the subject performing half squat where there is no marker placed on his body. But you can find the 3D coordinates and how the 3D coordinates are. So, on the right side, you can see the subject performing half squat.

The markerless motion capture system creates the 3D coordinates in 3D, three-dimensional surface for further quantification and analysis.

What are the hardware components needed for a motion capture system?

First, we need a camera, particularly the infrared camera. Then, we need the cables to connect the camera. If we are using minimum eight cameras or more, so these cameras' cables has to be synchronized, and the camera cables has to be connected with the synchronized unit or synchronization unit or in other words we call it as sync unit then, we have to fix the retroreflective markers that is passive markers on the body of the athletes and then we need a computer. So, to summarize we need the IR cameras with tripod and then the cables and the computer with software and then sync unit in short the retro reflective markers has to be fixed on the athlete body and then we need a calibration kit, so the calibration kit is used to calibrate the capturing volume area where the athlete is going to perform any movement. So, these are all the hardware components needed for a 3D motion capture analysis.

[Next comes the **camera placement and setup**].

How to place a camera?

First, we use the Daisy-Chain method. So, we have already discussed about what is Daisy-Chain. So it is minimal number of cameras where one camera is being connected with the other with the same cable because the power supply is passed from one camera to the other.

So, we do not need any multiple number of cables. And you can see here, so one camera is connected with the cable and another cable takes the power and data and is connected with the other camera. This is how we can reduce the size or length of the cable or number of cable and then we use power and data cable. So, both power and data cable are coming with as a single cable.

So, that helps us to do the faster setup and with maximum efficiency. Let us see the importance of camera positioning. The cameras are positioned so as to see the marker. As a principle, any marker should be seen at least by two cameras.

This type of principle helps us to track any marker so that if the marker is occluded or hidden, so it can be tracked by the other camera. So, this will avoid the number of repeated trials by the athletes. And, so I can see the camera seeing the marker and The other camera also sees the marker. So, the marker has to be seen by minimum two cameras for a better movement capturing and analysis.

[Next comes calibration]

Calibration:

Calibration is an important part of a motion capture system because, the camera capturing area has to be calibrated because the cameras may not know what is the size of the calibration area and what is the length, width and does not have any reference. So, the calibration is done to make the cameras to understand what is the actual length and width of the capturing area. And here you can see the capturing area where the calibration is being done. So, the calibration is done to locate where the markers is in with respect to XYZ direction.

What are the tools required for a calibration?

First, we need a Wand calibration. The Wand is coming with the markers at the base and then L-frame is required. So, L-frame has the marker for denoting the origin.

Next comes the **height marker and then the length**. So, at the bottom you can see the L-frame. The L-frame has its the origin and water level and further it has two markers which will denote the length and the height. And the L-frame can be adjusted with level adjustment screws on both the ends. And both the L frame and van can be placed in a calibration box. So, now comes calibration volume.

What is the volume of area?

Where we calibrate where the athlete can perform an activity. And here you can see the box area is the calibration volume.

So, what are the movement the athlete does within this calibration volume that is being tracked and captured by these infrared cameras through its software? That is the basic component where everyone should understand. It is a marker and the number of markers, the bony segments. So, it needs a trained personnel to fix the markers on the athlete's body. That is what we are going to see here.

You can see in this picture with different markers. So, predominantly it is with two colors. One is white, another one is yellow. You can see the markers being placed on the subject in different body marks. Right from the head, shoulder, elbow, wrist and then hip, chest, then thigh, Knee, ankle, and foot. So, there are a minimum of 41 markers required to capture any athlete using a motion capture system, particularly an optical motion capture system. Here, you can find some of the markers which are given in yellow color. So, the yellow-colored markers can be used only during a static trial. So, when it comes to a dynamic trial, these markers have to be removed. And, at minimum, there should be 41 markers to carry out flawless 3D motion capture of the athlete. So, here you can see the table, the display names, and location. So, the head front is the forehead above the nose. So, you have to fix the first marker above the nose.

Then come the head left and head right. So, this comes with a headband. So, it is easy for any person to fix the markers above the ear. And then, left shoulder top and right shoulder top. That is the acromion process, the bony prominence. And the two markers has to be fixed on right as well as the left. Then elbow in and out. So in the elbow, the outside of the elbow bony prominence. So you have to fix one marker at the same time the inside of the bony marker. Then next comes elbow and then wrist. Wrist in and wrist out. And here you can see all the display names and the location.

Whether it is chest or waist or thigh or knee out and knee in. But one thing we should keep in mind that any subject who is going to be assessed we have to first get the marker placed on the athlete's body. At the same time you have to conduct static trail and followed by the dynamic trail. During the dynamic trail the yellow colored markers may be removed by the subject which is not necessary.

[Thank you, and see you in the next video].