Kinematic Analysis

The basis of a kinematic analysis has historically been the camera. A common technique to perform a kinematic analysis has been to record the movement using a video camera (or more than one) and the 'digitizing' the movement for each frame of video. Although there are technological advances that allow for kinematic analysis without the use of cameras (e.g., using accelerometers and gyroscopes), understanding the digitizing process is critical.

The term 'digitizing' is used to describe a process of taking an image and creating spatial coordinates for each frame of video. Figure 1 illustrates a single frame of a video with reflective markers placed on specific anatomical landmarks.

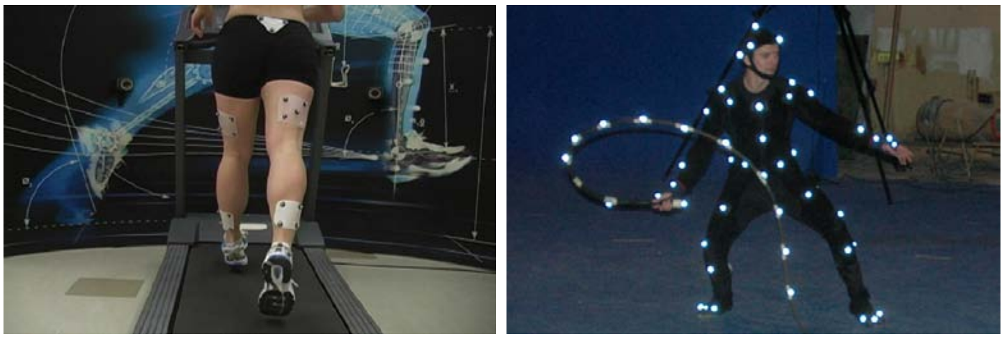

Figure 1: Using reflective markers to track movement.

Let's get started by talking about different digitizing systems. First, we will record two dimensions (2D) of a movement using a single camera … that is, we can get (x, y) coordinates. For example, Figure 2 is an illustration of an image from a single camera and we can record vertical and horizontal movement. A three dimension (3D) analysis is done by using 2 or more camera … sometimes as many as 12 cameras. We will typically refer to this type of system by the number of cameras … e.g., a 6 camera 3D motion capture system. A 3D kinematic analysis will yield spatial information in three dimensions (i.e., x, y, z). There is a lot of math involved in creating the 3D coordinates – for now, it is important to know that the process of yielding the coordinates is the same as the process for yielding 2D coordinates with the exception that the 2D coordinates for multiple cameras need to be combined in a way to yield all three dimensions.

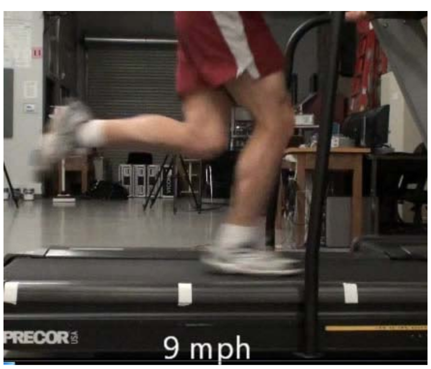

Figure 2: Image taken from a single camera.

Motion capture systems can be considered 'manual' or 'auto' digitizing systems. Manual systems are just like what they sound: The user manually selects specific landmarks for each frame of video and the (x,y) coordinates are returned for each selection. An autodigitizer differs in that the software is programmed in a way to automatically track specific landmarks.

There are advantages and disadvantages to each type of system. The advantages of manually digitizing is that the user can intelligently select specific locations (even if a landmark is hidden from view). The disadvantages include that the user can make selection errors and the time to manually digitize a video record can be long. For example, a typical sample rate of a camera (which tells us how many pictures a video camera takes each second) is 30 Hz. We use ‘Hz’ here as units to represent ‘frames per second’. If a movement takes 2 seconds to complete, there would be 60 frames of data … and that is for a single movement! If the movement is done several times, manually digitizing can take a long time to complete.

The advantage of an autodigitizing system is that the time to process is short. The disadvantages includes that sometimes the software makes an error in selecting the landmark. Also, there are times that landmarks are hidden from view. For example, if tracking the hip during walking, the hand will typically block the hip from view when watching from the side.

Digitizing often involves placing markers on specific landmarks. For manual digitizing, this is not necessary but can be helpful to the user when digitizing each frame. Autodigitizers need to have some way to recognize landmarks and many systems use ‘passive’ markers. These types of markers are simply reflectors that the camera can pick up. ‘Active’ markers may be some type of LED (Light Emitting Diode) that is tracked by the system (Figure).

To get started with digitizing, first you need to record the movement. Camera set up is critical to digitizing. For a good 2D analysis, the camera lens needs to be parallel to the plane of motion of interest. Or, in other words, the axis of the lens needs to be perpendicular to the plane of movement of interest. For example, if you are interested in how the knee flexes and extends during running, you would need to set the camera up in a way to record sagital plan movements. So, the camera would need to be set so the lens is parallel to the direction of movement (or, the lens axis is perpendicular to the movement). If the camera is not set up correctly, there will be errors in the process right from the start. The knee angle cannot be determined accurately or correctly when the camera is not positioned correctly.

It is important to set an appropriate frame rate for the movement. As mentioned earlier, a typical camera records video at a rate of 30 frames per second (i.e., 30 Hz). High speed cameras can record frames at faster rates … 60 Hz, 120 Hz, 200 Hz, 1000 Hz or even higher. The time between each frame is a function of the camera rate … for a 30 Hz camera, there is 1/30th of a second between frames. For a 1000 Hz camera, there is only 1/1000th of a second between frames. If a movement takes 2 seconds, a 30 Hz camera will record 60 frames of data while a 1000 Hz camera will record 2000 frames. Figure 3 illustrates a time lapse image of someone completing the pole vault. Each image is 1/30th of a second apart. If the frame rate is reduced to 60 Hz, you would only have 3 images (vs. 6).

Figure 3: Time lapse someone completing the pole vault.

The frame rate selected has to be made with some thought as to why the analysis is being done. If the analysis is done only to look at knee flexion extension during running, a 30 Hz camera would likely provide enough detail. If the analysis is being done to look at how the foot strikes the ground, a camera with a faster frame rate may be required.

Other things to consider with setting up a camera is how large of a field of view to include, making sure the entire movement and all landmarks can be identified, and checking the amount of light (especially when using reflective marker). If the camera has a zoom lens, it is a good idea to move the camera back and zoom in on the field of view. Finally, it is best to keep the movement of interest located within the center of the image. Lens imperfections can have a more pronounced influence at the edges of an image.

When markers are used, some care should be taken in considering where to place the makers. For example, if it is important to digitize the 'knee', one option is to place the maker at the knee joint center. That approach works well for joints are true hinge-type joints … but the knee joint center can move when large range of motions are included. Another approach would be to place two markers on the thigh and two on the leg and then mathematically identify where these two lines intersect and use that to determine the knee joint center. Figure 4 illustrates two techniques for placing markers on the body to measure knee angle. In both examples, it is best if markers are placed on bony landmarks in order to minimize the amount of movement there is to a marker due to soft tissue movement.

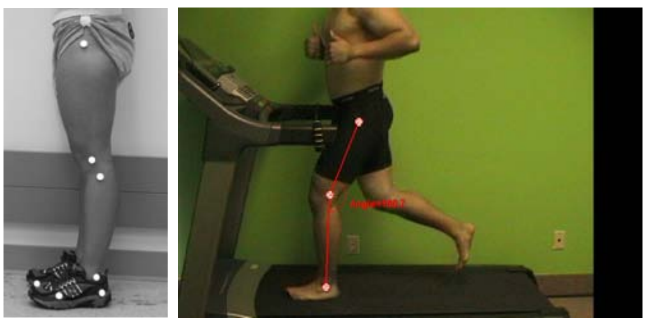

Figure 4: Illustration of different ways to use knee joint markers.

Once camera frame rate has been determined, camera set up is completed, and markers have been placed, it is important to record a known distance in both the horizontal and vertical directions. This is done simply by placing a meter stick (or some appropriate known length in the field of view) and using a level to hold the stick in the two directions while video is recorded. The known length should be held in the same position as where the movement will occur.

Once the known length is recorded, it is important that the camera is not moved. If the camera is moved, it is important to record a new known length. At this point, the movement of interest can be recorded and played back for digitizing purposes. To digitize, a reference frame must be created and then the coordinates of each landmark are recorded within that reference frame.

A data table is created so that each row represents the coordinates for the marker of interest.

Frame	Time	Knee x	Knee y

These position data can then be used to calculate velocity and accelerations in order to create a total kinematic data set.