DIY BIOMECHANICS

@NYU ITP

Key: closed source open source

MOTION CAPTURE

Motion capture, simply, is tracking/ recording the movement of objects or bodies. Now why would you want to do that? The best example? Avatar! By capturing motions of people or objects, we can calculate exact position in 3D space or state of the object at each moment during its captured motion and use this information to study about the mechanics behind the motion, or to control a number of things- as in Avatar's case, the movements of actors control the animation character. We also see motion capture being used in-

→ Video games: for real-time control of characters with our body's movement like this!

→ Medical & science field: for studying and analysing physics of human motion e.g. biomechanics study in sports and rehabilitation

..and a number of other applications.

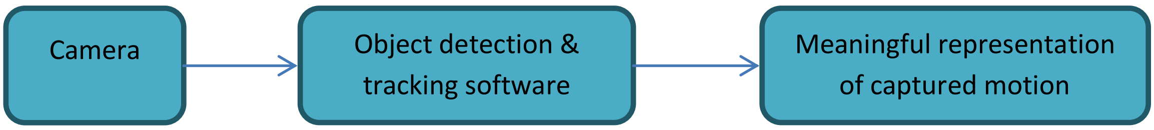
All these applications capture the motion of a person by tracking either of the two (or both) parameters involved in a body's movement:

1. Kinematics- Parameters of the moving body's trajectory- e.g. the path followed by my leg while kicking a football
2. Kinetics- Forces involved in causing the motion- e.g. the torque (a type of force) with which I swing my leg to kick the football

Let's have a look at how these parameters are measured:

1. Kinematics based motion capture

1.1. Optical systems:

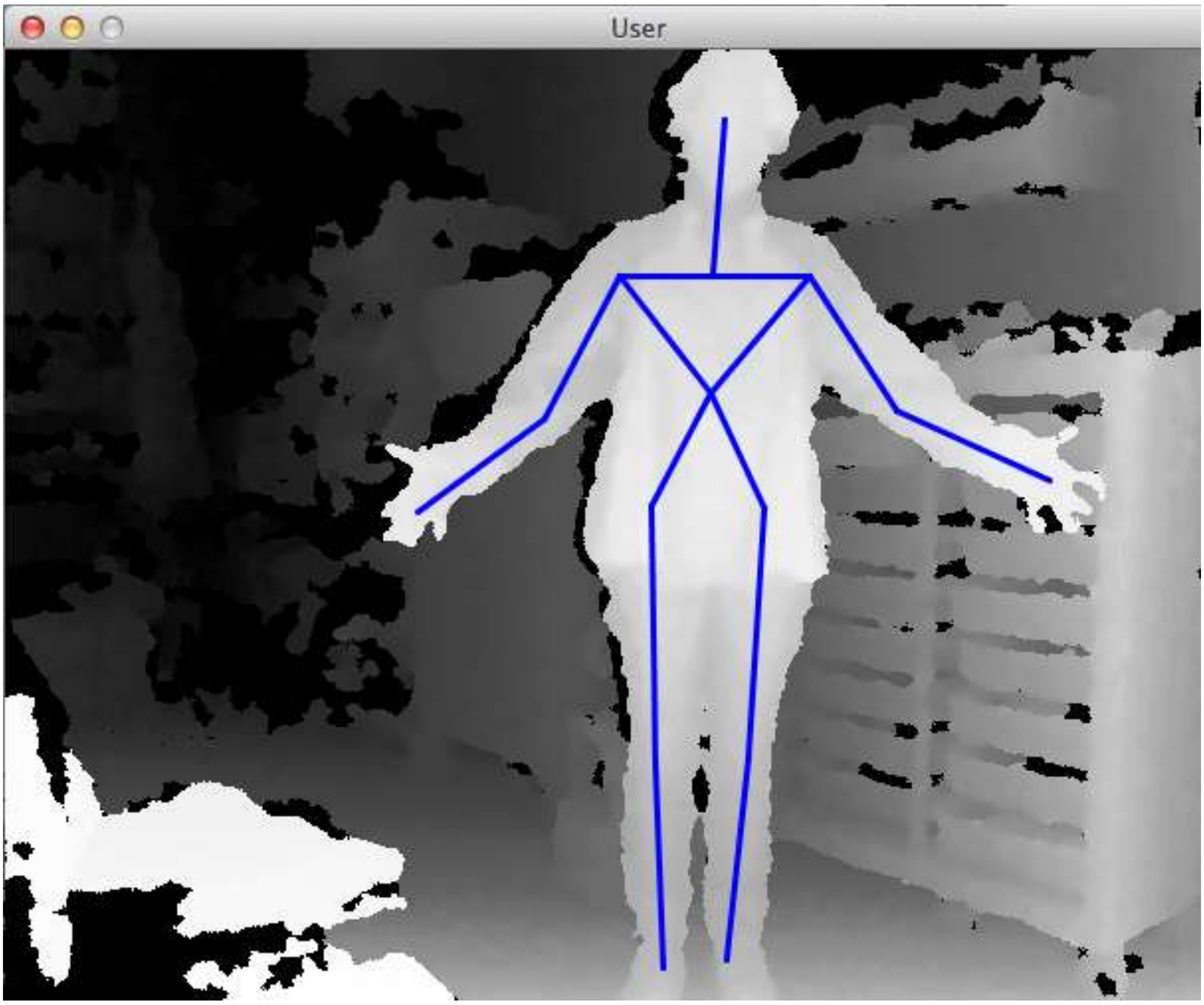


These use normal cameras (usually HD) or most commonly, depth sensing cameras to capture the motion. This video is then sent to software which computationally detects objects and starts tracking their positions, once detected. And lastly, the tracked elements and their positions are represented appropriately either as a visual or a dataset.

Let's look at the commonly used motion capture systems:

1.1.1. Microsoft Kinect: /

..is a depth camera that uses IR projection to detect the distance of objects from it. This depth image makes it easy for the supporting software to detect the "skeleton" of the person in front of it i.e., tell where the joints of the person are. There are various SDKs and libraries that track this skeleton and process the data from the camera to capture motion of the person. You can even connect multiple Kinects to get a better capture image (multiple Kinects eliminate 'shadow regions' in the single connect system)



Greg Borenstein's Making Things See is a great resource for learning about using Kinect with Processing to do skeleton tracking.

Resources for using Kinect with different platforms:

SimpleOpenNI for Processing
Zigfu Development kit for JS/HTML5, Unity 3D, Flash
Kinect for Windows SDK by Microsoft for C++, C#, Visual Basic

Kinect is probably the cheapest option to perform motion capture with a good degree of accuracy. You can do motion captured character animation fairly easily using readily available software like:

- iPi Studio by iPiSoft: it allows you to record a video, detect skeleton motion and apply the motion to any 3D animated character. Here's a great intro video on how the software works. It's pretty easy but it loses track of your body once in a while. Using multiple cameras might solve this problem; you can also manually correct the tracking.
  Windows only.
- iClone by Reallusion: it allows real-time control of 3D characters. It's extremely easy to use but is Windows only as well.

1.1.2. Vicon

..is a state of the art system that uses marker based tracking of objects in 3D space. The marker dots attached to a body (as shown in the picture), reflect the IR radiation emitted by the LEDs. All other light is filtered so that the system only recognizes the dots. In s/w, the images taken from all of the cameras are used to construct a 3D representation of markers.

Figure 1 Source: Scott Ham's site

This tracking system consists of very high resolution depth cameras (usually 8-12 nos), dedicated hardware and software that can be integrated into any working environment so you can exchange data motion capture data with third party devices like force plates, EMGs, eyetrackers, etc.

1.1.3. Organic Motion

..is a markerless tracking system that uses sophisticated software to detect & track motion recorded using **regular cameras**.

1.1.4. Qualysis

..a lot like Vicon but dedicated hardware for use under various special circumstances like motion capture under water, at outdoor locations and during MRI scans!

1.1.5. Leap Motion

..is a small depth sensing device that detects hand gestures- tracks fingers up to $1/100^{th}$ of a millimeter. It has 150^{o} field of view and can be plugged into your computer via USB. Currently, it's only available for developers. You can access developer tools by signing up on their website.

<LEAPs in the ER are missing>

1.1.6. Intel's Creative Interactive Gesture camera ($149)

..is a new IR-based camera (capture range of 12 inches), with microphone array, for doing gesture & voice recognition. The SDK supports Processing, OpenFrameworks, Unity 3D, and many other platforms; but is Windows based only. Some applications developed at a hackathon at NYC.

As of June 30, the SDK still had some bugs. If the latest one doesn't work for you, try using one of the earlier ones (works 95% of time). Also, just like the Kinect, the raw data is pretty jittery; use a low pass filter to smooth out the data.

Additional info on Optical motion capture systems:

→Cool applications by ITPers:

- Yin's dance-based calligraphy
- Kyle McDonald's *Caricature* using facetracking

- Dollee Bhatia's telepresent robot, Robhatia
- James Borda's game, Dragon
- Aaron & Mike's mesmerizing installation, Firewall
- Lei & Mary Fe's facial expression-based performance, Night Rest
- Sanniti's interactive audio-visualization, Dance-ize

→ Cons of optical motion capture:

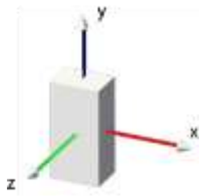
- Needs large capture area, while being limited to the cameras' field of vision
- Reduced accuracy while capturing high speed motion

→Some motion capture studios in NYC:

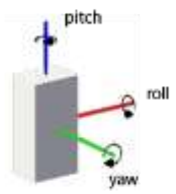
1. NYU Movement Lab
2. WorleyWorks ($6000 per MoCap session)
3. Motion Capture NYC

1.2. IMU systems:

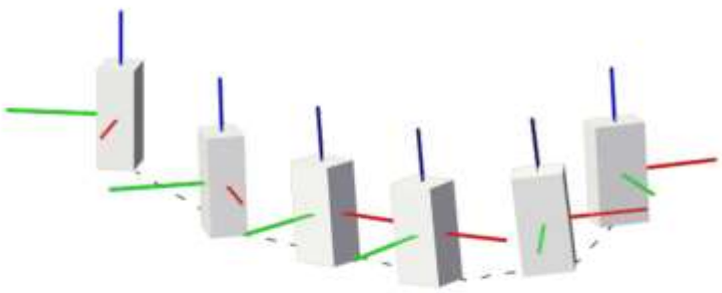
Inertial Measurement Unit is an electronic device which uses a combination of accelerometer, gyroscope & magnetometer(optional) to predict the location & orientation of the device in 3D space. The prediction is done by calculating linear displacement (using accelerometer data) and rotational displacement (using gyroscope data) of the object, from a reference point (magnetometer acts like a magnetic compass to provide a reference frame). [1]



Linear displacement



Angular displacement



Trajectory of object

So, by attaching such a device to an object we can track the motion of the object. To capture motion of a person, a number of such IMUs are attached on the person's body in such a way that the combined outputs from all the units gives detailed tracking information of the whole body.

Here's a great video showing the IMU's motion capture ability

A great advantage of these systems is that they eliminate the restrictions placed on the capture area (it can be as small/ big as you want) and there's no problem of occlusion. But they have their own set of problems[1]:

- IMUs are affected a lot by Electromagnetic interference
- Accelerometer readings start to drift noticeably after a short period

Gyroscopes sometimes enter a position called the "gimbal lock", which makes it lose track of orientation for a brief moment. Many solutions have been developed to tackle these problems successfully, e.g., use of special filters and algorithms diminish the above stated accelerometer & gyroscope errors.

Some of the popular, commercially available IMU systems are: Xsens, Motion Node, Synertial (Animazoo). These systems use wireless IMUs (have wired option as well) with sophisticated software and communication technologies to provide accurate data. XSens also provides an IMU based motion capture suit. All the systems provide capture data in form of raw & calibrated sensor values as well as skeleton motion data for animation (.bvh, .fbx) and biomechanical analysis (.c3d). Synertial also has an IMU glove for hand and finger tracking.

There are some initiatives on DIY IMU based motion tracking. Here are some useful resources:

- OpenIMU

- FreeIMU (great resource but no longer active. Refer this page for similar project with compatible h/w & s/w)

- Sparkfun's IMUs..come with good documentation. (Here's an Arduino library for the MPU 9150 mentioned)

- 9 DOF inertial orientation estimation

- DIYDrones & mbed.org have some useful info on using IMUs as well

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How about a combination of optical & IMU-based systems? Yes, it's been done: http://www.informatik.uni-freiburg.de/~stachnis/pdf/ziegler11iros.pdf

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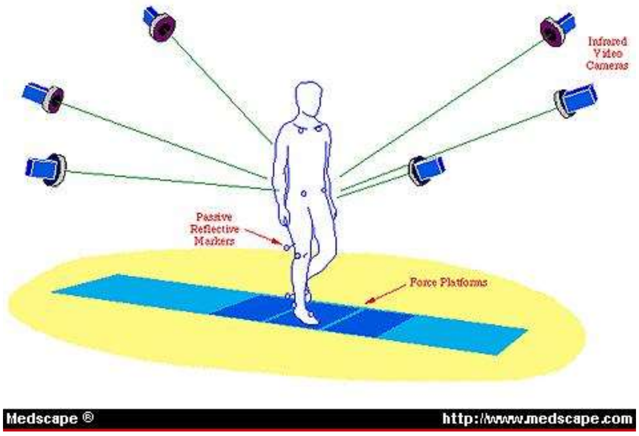
Lots about accelerometers, gyroscopes & IMUs on ITP Sensor website

2. Kinetics based motion capture:

Kinetics of motion involves analysing the forces & moments taking part in the motion. Naturally, the crux of such capture systems is a force sensor. In these systems, forces exerted by a person while performing various activities are recorded and analysed for various purposes such as: in biomechanical studies for gait & balance analysis, sports performance tracking and also in touch screens and video games. The most commonly used sensors for measuring force are:



→ Hall effect sensors: These are basically magnetic field sensors- a change in magnetic field produces a proportional voltage at the output. So, if an effect of force incorporates magnetic field, a hall effect sensor can be used- e.g., AMTI force plates (mentioned below) have spring elements integrated in them which deflect when acted upon by a force, affecting a change in magnetic field created by the integrated magnets.[2]

→ Strain gage: is an arrangement of a conductive strip such that small amount of force exerted on it creates a large change in resistance across the strip.

→ Piezoelectric sensors: are crystals that produce voltage when exerted with pressure

An intro video to gait analysis

Some popular resources for force sensing:

2.1. AMTI (Single force plate system ~$13,000; has 15% student discount)
Provides high quality force plates, force sensors & custom instrumented equipment (e.g., treadmills with force plates) that are used mostly in biomechanics research. Use both hall effect sensors & strain gages in their products. They provide software particularly useful for biomechanical analysis like gait studies.

2.2. Bertec (Single force plate system ~$10,528; Balance plate ~$4,550)
Provide products and services similar to AMTI with addition of special jump plates and force bars. Strain gage technology is used in all products. A balance plate measures only vertical force & center of pressure while a force plate measures the shear forces as well (Fx, Fy, Fz, Mx, My, Mz)

2.3. Kyowa
..is a general manufacturer of stress measurement equipment – with speciality in strain gages

2.4. Kistler
..is manufacturer of high precision torque, displacement, pressure & force sensors. These sensors are built in various configurations to fit different application needs.

2.5. Tactonic technologies Inc. (2'x2' Master tile- $2500; Slave tile- $1000)

..have developed pressure sensors that provide location of the pressure points on them in addition to the intensity of pressure. They're particularly developed to be used as a human- computer interface. Any material can be used to apply pressure (the stylus) & hence can act as a better alternative to touch screens.
Features: Efficient multi-finger touch detection, No EMI, provision of a control panel designer app which allows users to develop their own front panel/ controlling interface.
→These tiles might be a very good & low-cost alternative to the ones mentioned above. Since it is low cost and easy to set up, we can have a small 'walkway' made of these tiles for gait analysis- which eliminates the cumbersome procedure of having the subject hit the right plate.

[NOTE: During gait analysis, usually, only 2-3 force sensors are used because of the cost and installation difficulty. This means that the subject has to hit the force plates correctly & completely, while walking normally- which is difficult to achieve; requiring a lot of tries**]**

2.6. Wii Balance board
..is a controller designed for Nintendo's Wii Fit games. It uses four pressure sensors (load cells) to calculate the center of balance of the person standing on it. At a cost of $99 (for the game kit), it can be a good alternative to high-cost force plates described above if it can provide reliable pressure data; and a study has proved that it can: http://www.ncbi.nlm.nih.gov/pubmed/20005112

2.7. General pressure sensors:
A lot of security companies provide mats that can sense presence of person by sensing pressure on them. Apart from security applications, they're also used in biomechanical analysis for identification of plantar pressure (Tekscan mats).
A low cost alternative to these pressure mats is FSRs
An extremely cheap alternative to these mats is conductive foam!

2.8. Other kinetic-based systems:
Hoggan's microFET- handheld force evaluation & testing device

Biodex's dynamometer systems

References:

[1] “Inertial measurement unit,” *Wikipedia, the free encyclopedia*. 27-Jun-2013.
[2] “Hall Effect and Strain Gage Sensor Technology for Multi-axis Force Plates and Force Sensors | AMTI Products.” [Online]. Available: http://www.amti.biz/fps-sensor-tech.aspx.