

Exercise & Sports Biomechanics
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Week 08
Lecture 36
Accelerometers

[Hello, everyone! Welcome back to this course. In this video, you are going to explore the next hardware tool called an accelerometer. In this image, you are seeing one sensor called an IMU].

What is an IMU?

An IMU is an inertial measurement unit. It is a combination of an accelerometer, a magnetometer, and a gyroscope. So, an IMU is the combination of all three. Nowadays, most people have started using smartphones. You can see the image in portrait mode.

If I rotate the mobile, it automatically changes the direction of the image to landscape mode. Do you know why?

This is because your phone has an accelerometer sensor. In this video, we will explore how the accelerometer works and how to collect data from the sensors.

What is a sensor?

A sensor is a device that helps us detect and measure information. Simply put, a sensor is like a human sense. But it is for the machine. For example, the sensor helps to see through the camera and helps to hear through the microphone. That is how the sensor works.

How these sensors are applied in real-world applications?

If you have traveled via flight, there will be a constant notification that you cannot smoke in the lavatory, right? So, in the flight, they have used the smoke sensor. If somebody starts smoking in the lavatory, then the smoke sensor detects it and indicates that somebody is smoking inside the washroom. The next one is the Proximity Sensor.

Proximity Sensor:

If you are traveling by car and trying to park the vehicle somewhere, if you get too close to the wall, there will be a beep sound. This proximity sensor helps to determine whether the distance between the car and the wall is close enough or not.

The next one is, if you want to check your body weight, Do you know what kind of sensor we are using nowadays? It is a force sensor or pressure sensor, which helps us to measure body weight and pressure distribution when we stand on the force plate.

[The next one is the motion sensor].

Motion sensor:

Motion sensor helps us to detect movement changes. There are so many sensors with various applications, but now we are going to focus only on the accelerometer sensor.

What is an accelerometer?

It is a sensor that measures acceleration, which is the rate of change of velocity. Simply put, it helps us to understand how fast an object or a person is speeding up or slowing down and in which direction it is moving. I hope this concept has been covered in previous lectures, but now we are practically implementing it via hardware and software.

Three major types of accelerometers:

They are MEMS capacitive accelerometer, Piezoresistive accelerometers and piezoelectric accelerometers. The first one is the MEMS accelerometer.

What is meant by MEMS accelerometer?

M E M S means micro electromechanical system. This type of accelerometers are tiny but powerful sensor found in your smartphones and fitness trackers like your smart watch.

How MEMS accelerometer works?

Inside the MEMS accelerometer there is a tiny movable mass. You can see that in the orange color which is moving and it is connected to the device using a microscopic springs in both the ends. When the device experiences the acceleration, which means if the subject is walking or moving the accelerometer, the mass shifts slightly in the direction of the force. In addition, the movable mass is positioned in such a way between the fixed capacitor plates. As the mass moves, it changes the distance between the plates altering the capacitance.

This change in capacitance is measured and converted into acceleration data. The springs at both ends help to return the mass to its original position once the motion stops. The capacitance change is converted into an electrical signal. And processed by a microcontroller to determine speed, tilt, or any kind of motion. All these MEMS accelerometers are small.

They do not require a lot of power. And they are cost-effective when compared to the other two types of accelerometers.

[The next one is the piezoresistive accelerometer].

Piezoresistive accelerometer:

Inside the accelerometer, there is a small mass attached to the beam. This is the beam; the black-colored one is the beam with a strain-sensitive resistor. It is already noted here that when the device experiences acceleration—meaning when the accelerometer moves—the mass moves by applying force on the beam.

The force causes the beam to bend slightly. You can see here that it stretches or compresses the strain gauges. This bending changes the electrical resistance of the strain-sensitive

resistor. The change in resistance is converted into an electrical signal, which is proportional to the applied force. Through this method, we can determine the acceleration of the object.

Because piezoresistive accelerometers can measure both static and dynamic acceleration. They are commonly used in car testing and many biomechanical applications.

[The last one is the piezoelectric accelerometers].

Piezoelectric accelerometers:

Inside the accelerometer, there is a small mass attached to a piezoelectric crystal, these are the piezoelectric crystals. When the device experiences acceleration, as the accelerometer moves, the mass pushes or pulls against the piezoelectric crystals. These piezoelectric materials deform slightly under pressure and generate an electric charge proportional to the force applied, which means the higher the force, the higher the movement. The generated electric charge is sent to the circuit, where it is converted into an electrical signal. The signal is then analyzed to determine the acceleration of the object in motion. Since piezoelectric accelerometers react very quickly, to all movements, they are used in vibration analysis and especially in sports tracking.

[So far, we have covered different types of accelerometers. What exactly is it measuring? It is very simple: acceleration, right?]

Let us do some mathematical calculations:

Every time we address acceleration as 'a', so, what is the formula for acceleration? It is the change in velocity divided by the change in time. $a = \frac{\Delta v}{\Delta t}$

This(Δ) is known as delta, which means 'change in.' If we rearrange this formula to solve for velocity, why do we need to solve for velocity?

With only the acceleration data, we cannot interpret much information. So, from the acceleration data, we can decode much information. The first one is velocity. So, if I take the change in velocity as one side, then it is going to be acceleration multiplied by the change in time. $\Delta v = a \times \Delta t$

So, you can always write velocity as equal to AT. $v = at$

Let us take one example. If the runner has an acceleration of 2 meters per second squared and a time of 5 seconds, then what is the velocity? Simply, you can multiply 2 by 5 to get 10 meters per second.

$$a = 2 \text{ m/s}^2$$

$$t = 5 \text{ s}$$

$$v = ?$$

$$2 \times 5 = 10 \text{ m/s (as } v = at)$$

So, based on the acceleration data, you can identify the velocity.

Based on the acceleration formula, you identified that, $v = at$. So, this will be the first equation you need to remember. The second step is you need to compute the average velocity, which means it is the initial velocity plus the final velocity divided by 2. In this case, the initial velocity is 0, and we have found that the final velocity is going to be AT divided by 2. So, which means the average velocity is equal to AT divided by 2.

$$\text{Average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

$$== \frac{0 + at}{2}$$

$$V = \frac{at}{2}$$

Now, what do we have to compute? We have to compute the distance or displacement. So, the basic velocity formula is equal to distance or displacement divided by time. If we rearrange the velocity formula, the distance equals velocity multiplied by time.

Now, our major goal is to identify **what the distance is**.

Now, we have already computed the velocity. The average velocity is equal to AT divided by 2 multiplied by T , which means we can make it half AT squared, which is the distance.

$$v = d/t$$

$$d = v * t$$

$$= \frac{at}{2} \times t$$

$$d = \frac{1}{2} at^2$$

Let us take the same example. So, what is the acceleration here?

2 meter per second square. Time is 5 second. If we compute here is the off the acceleration is 2 and 5, which is 25. So, if we cancel out, it is the 25 meters.

$$a = 2 \text{ m/s}^2, \quad t = 5 \text{ s}$$

$$d = \frac{1}{2} at^2$$

$$= \frac{1}{2} \times 2 \times 25$$

$$d = 25 \text{ m}$$

So, from the acceleration, we have identified the velocity. Now, we have identified the distance.

The next one, we are going to compute **what is the force** based on the acceleration data.

You know from the Newton's second law of motion, $F = ma$. So, we will take some example. The hockey player is having the body mass of 70 kg. And if he is going to run or is running with a 3 meter per second square of acceleration. So, what we are going to do 70 into 3 which means 210 Newton.

$$F = ma$$

$$= 70 \times 3$$

$$= 210 \text{ N}$$

So, this much force is produced by the hockey player when he is running on the hockey field.

Lastly, we will compute **kinetic energy**.

Kinetic energy is half $m v$ squared. $KE = \frac{1}{2} mv^2$

So, we are going to compute this. What are the other equations which we have done previously? Velocity equals acceleration multiplied by time. If it is the average velocity, then it is AT divided by 2. And we have computed distance also. The formula is AT squared.

$$v = at$$

$$\text{average velocity} = \frac{at}{2}$$

$$d = \frac{1}{2} at^2$$

From the previous lectures, I hope you understand that kinetic energy is directly proportional to work. Without movement, there is no kinetic energy.

$$KE \propto W$$

So, **what is work?**

It is force multiplied by distance. We know the force $F = MA$, and we know the distance is half AT squared.

$$W = F \times d$$

$$= ma \times \frac{1}{2} at^2$$

Since we know V equals AT , if we square both sides, then it is going to be

$$v^2 = a^2 t^2$$

So, in this formula, it is already there: A is there, A squared and T squared are there, which means the A squared and T squared will be replaced with V squared. Now, if I rearrange this, it is going to be of m V squared.

$$KE = \frac{1}{2} mv^2$$

So, which is the kinetic energy.

We will take another example. If the hockey player has a mass of 80 kg and is running at 8 meters per second, which is the velocity. So, if we compute, it is going to be half into mass is 80 kg, into 8 squared. It is going to be 2560 J.

$$\begin{aligned} KE &= \frac{1}{2} mv^2 \\ &= \frac{1}{2} \times 80 \times 8^2 \\ &= 2560 \text{ J.} \end{aligned}$$

So, this much amount of energy was spent by the hockey player. So, from acceleration data, we got the velocity, from the velocity data, we got the distance, and we have already computed the force data. Based on all this information, we have computed the kinetic energy. So, imagine that with one sensor, we can do N number of calculations.

How the accelerometer sensor in your phone works and how to export the data?

For this, we need to install an app in the Play Store, which is the physical phone instruments. Once you download this application, you can able to see the first two is the acceleration without g, acceleration with g. So, what is g? Everybody knows acceleration due to the gravity, so g is 9.81 meter per second square. So, if i am opening the acceleration with g it will show three box which is the x axis, y axis, and z axis. At the top there is a play button once you press the play you can able to see the data is started recording and if you do not want you can able to delete the data.

Now basically, you are seeing the data in the x axis Y axis and Z axis. If you notice that the data is almost zero. And only the Z as we discussed, it is showing 9.81, which is the acceleration due to gravity. So, how the data is recorded? So, imagine that I have placed my phone on the table which is flat now then the top axis is a Z which is you are seeing 9.81 and that is the two more direction is there one is the forward and the sideward which is the X axis and Y axis So, currently the mobile is not moving. So that is why it is showing 0 and 0. As and when if I change the direction of the mobile, now you can able to see there is a changes in the accelerometer data in both the x-axis and the y-axis. In addition, if you want to see the absolute data, you have to select this button. So, you can able to see right now the mobile is flat. It is showing only 9.81 meter per second square. Now, if I am going to change the orientation of the mobile, then it is going to be increasing.

[Next, I am moving to multi].

You can able to see all the data which is in the accelerometer X, Y, Z. In addition to that, you can able to see the absolute acceleration also. The last option is the simple, which is the raw data. Now I am going to change the orientation of the mobile.

Now, you can able to see there is some changes in the data. I will pass the data and at the right top corner there is a three dots. Once I click that you can able to see there are multiple informations are there. The second one is the export data. Once I press the export button you can see the data can be exported in Excel CSV formats.

Once I press OK, the data will be downloaded and you can able to share the data via WhatsApp or email so that you can able to perform further calculations. Now, when it comes to acceleration without G, the interface is exactly the same. Now I will start recording the data of the acceleration. If you notice that all the X, Y and Z is maintaining in the zero. Which means with the help of gyroscope the data has been eliminated. Which data has been eliminated?

The acceleration due to gravity has been eliminated, so that you can able to see only the motion data. For example, if I am performing a biceps curl of one repetition and then I will wait for few seconds and then I will perform the second biceps curl. Only based on the graph itself, you can able to identify there is some movement, not specifically the biceps curl.

Based on this movement data, you can follow the same process which we have discussed before with the acceleration with the g and you can able to export the data and we can do all the calculations.

[Moving forward, let us create a mobile application specifically for Accelerometer]

Once you understand this concept to develop a small application, you can able to apply that in any sporting movements. For that, you need to go to MIT App Inventor and press the button 'Create App'. So, it will direct you to register yourself. Use your Gmail ID, and once you are done, you will be on the home page of MIT App Inventor. So, in this, I am not going into the depth of the interfaces. But I will show you a little bit of the interface, which will help you develop a small application in this app.

The first step is to create a new project. So, I will click on 'New Project,' and it is asking for the project name. I will type 'NPTEL' and then press OK. So, once it is opened, you will be able to see the screen directly. So, in this interface, on the left-hand side, you can see the palette.

Where you can see the user interface, layouts, and so much information on the left-hand side. And in the middle, you can see the viewer. Right now you are seeing the mobile view. And if you want to change the size to a tablet view or monitor size, it is up to you which one you are working on.

So I will stick on to the mobile size. And at the right hand side, you can able to see the properties, how these information should look like. So, as and when you are taking some

information from the user interface, then all the appearance and related information can be changed. For example, I will go to the user interface and I will drag the button on the screen. It is exactly moving to the left top corner. If I wish to change that I need to go to the screen and align horizontally. I am changing it to center, align vertical and changing into center. Now you can see this button right now in the middle. So by default, the background color is white and there is no background image. If you wish, you can change it. Now in the title, instead of screen 1, I will type NPTEL. You can notice that at the left top corner, the screen name has been changed to NPTEL. Now we have selected the button. Similarly, we can able to change all the functionalities over here. Right now, I will make the font bold and will change the size a little bit increase the size font size and background color is black I will give it yellow and it is showing the text color I will change it to red, so instead of text for button one I will type NPTEL and then press enter it will change.

Now, in the right top corner, there is an option called blocks. To develop an application, you need to give some kind of algorithms. Once you click on the blocks, there are so many functionalities are there, which comes under built-in.

Now, I am going to click the button 1. So, there are so many conditions and instruction blocks. The one which you are seeing in the orange colors are the conditions block and the one which you are seeing in the green color is the instruction blocks. Now, when button 1 is clicked, what exactly should happen? So, now you have given the condition. I will click on the button 1 again. Now I need to give the instruction for that particular button. What exactly I am going to do? I am going to set the button 1 as a text. So we are adding the text.

If I click the text and then it is an empty code where I can type exercise and sports biomechanics. If I run this application, so once I click that from the NPTEL, it will convert into exercise and sports biomechanics. Let us try that to run the application, and at the top, there is an option called connect.

There are three different ways to run the application:

The first one is the AI companion, emulator and USB. So, we will stick with the AI companion. Once I click the AI companion, there will be a QR code and the code which we can able to type in the mobile will be popped up.

Before that, there is a clear instruction that you need to download a mobile application named MIT AI Companion. So, go to the Play Store and download the mobile application. Once you have done that, you will be able to see the application on the screen. Once the app is opened, there are two options available.

One, I can use the scanned QR code. I can scan the particular QR code from the website, or I can type the six-character code here and proceed with further analysis. Now, let me scan the QR code. It will take some time. Once the installation is done, you will be able to see the mobile application now.

So, we have done NPTEL with the yellow background and red color. Now, what I am going to do is click on NPTEL. As soon as I click it, it converts into Exercise and Sports Biomechanics. So, this is how you can test the entire mobile application.

Let us go back to the website. At the top right corner you can see there is another button called 'Designer.' So, I am going to design again. Instead of the user interface, I am going directly for the sensors. So, I am not going to deal with anything else.

The first sensor is the accelerometer sensor. Just click on that and drop it on the screen. If you notice, it is not showing on the screen; instead, it is visible at the bottom. It mentions that it is a non-visible component. All the functions will work, but it will not be visible on the screen. So, if I click on the accelerometer, it asks for the sensitivity—whether it is weak, moderate, or strong. I will keep it moderate and then go back to the blocks.

Now, if I click the accelerometer sensor button, there are only two condition blocks, and the remaining are instruction blocks. I can either use the data of X, Y, Z, or I can detect the shaking of the mobile and do something with that. So, I am going back to the design, and in the user interface, I am taking the label Label 1, Label 2, and Label 3. So the first one is going to be the X axis. The second one is going to be the Y axis. Third one is going to be the Z axis. So if I want to increase the size of it, so you can increase the size. I am going to change all the three axes to font size 20. Now I am going to blocks again and I am going to click the accelerometer sensor, I will take the acceleration data so here I can do X, Y and Z. So click on the label button, you can able to see number of instructions and I will choose the set label 1 with the text, so if I right click that I can duplicate. I will duplicate again, so I will get label 1 2 and 3. If you click on the X acceleration data, you can get the X acceleration, Y acceleration and Z acceleration. Once it is done, the same process, you have to run the application. Now you can able to see the values.

Now the mobile is on the table, the value of X and Y is 0, and the Z axis is 9.81 approximation. If I am changing the orientation of the mobile, then you can able to see there is a change in the X axis and Y axis. This data will be recorded and you can perform much better than the previous one. Why?

So, here you can able to define the threshold. It is a kind of app. You can fit your mobile onto your shoulder, onto your back and you can perform the exercises and you can able to identify what exactly you need.

If I am pressing the NPTEL again, so it will change to exercise in sports biomechanics. So, the entire application works well. You can develop your own application to identify it can be either walking it or performing a squat or you can make it for the biceps curl. It can be anything. So just try it.

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