SECTION

3

SENSORS AND ACTUATORS 1

Principles of Robotic Systems

Sensors and Actuators

INTRODUCTION

This section focuses on robotic sensors and explores the principles behind their operation and how they draw inspiration from nature. It examines the dynamic relationship between humans and robots by analysing the critical role of sensors in robotic perception, like how living organisms gather information about their environment. It also focuses on linear sensors, their diverse functionalities, and the importance of calibration for achieving accurate and reliable measurements. This knowledge will help you to explore how to make use of linear equations to calibrate these sensors thereby ensuring optimal performance in robotic systems. You will apply this knowledge to critically assess real-world scenarios, enabling informed decision-making in the field of robotics and automation.

At the end of this section, you should be able to

- Draw a parallel relationship that relates the coordination of senses, brain and moving parts in living organisms to the coordination of sensors, processors, and actuators in robots.
- Discuss the scientific principles underlying the operation of sensors
- Observe varying outputs of different linear sensors and explain the variations observed.
- Apply knowledge from linear equations to calibrate linear sensors and to scale sensor readings to fit within a desired max-min range.

Key Ideas

- The coordination of sensory organs, the brain, and body parts enables living organisms to perceive their environment, process information, and respond effectively. Similarly, the coordination of sensors, processors, and actuators in robots allows them to sense their surroundings, analyse data, and perform tasks accurately.
- Just as eyes, ears, and skin detect visual, auditory, and tactile information in living organisms, robots use cameras, microphones, and tactile sensors to gather similar data.
- Robots use actuators that mimic muscle movement, hydraulic systems, and other biological mechanisms to achieve motion and perform tasks.
- The brain processes sensory information and makes decisions in living organisms. In robots, processors serve this function, analysing sensor data and controlling actuators accordingly.
- Sensors convert physical signals like light, sound, or pressure into electrical signals.

- Sensors comprise several components: a sensing element, a transducer (converts physical quantity, energy into another form of energy such as an electrical signal) and a signal processor.
- The calibration of sensors is crucial for ensuring accurate and reliable measurements, compensating for differences in manufacturing and environmental conditions.
- Sensors used in robots are not perfect and the values they measure might not be as accurate as they should be. Calibration is the process of fixing that to make sure the sensor readings are accurate.
- Calibration adjusts the sensor's output to reflect the measured value more precisely. There are different ways to calibrate, but a common method is two-point calibration. This involves taking readings at two extremes (like very bright and very dark for a light sensor) and adjusting the sensor's response across that entire range.
- Scaling is like adjusting the volume on a speaker. Scaling takes the sensor readings and adjusts them to a specific range, often 0-100, for easier use in robot programming. This way, the robot can understand the sensor data and react accordingly.
- By calibrating and scaling, you teach your robot's "senses" to be more accurate and reliable. This allows the robot to make better decisions based on the real world, leading to smoother navigation and smarter actions.

EXPLORING NATURE-INSPIRED SENSORS, ACTUATORS AND CONTROLLERS

In this lesson, you will explore the scientific principles behind the operation of different robotic sensors. You will learn and understand how sensors convert physical stimuli into electrical signals that robots can process. You will also look at the varying outputs of different linear sensors and explain why these variations happen. Understanding these principles will help you design and use sensors effectively, allowing robots to perform a wide range of tasks accurately and efficiently. Prepare to dive into the exciting world of robotic sensors, where technology and perception come together to create intelligent machines.

Similarities Between Robots and Living Organisms

You should know the different subsystems of a robot and how these subsystems can be compared to the human sensory and muscular systems. The robot sensing subsystem is similar to the sensory organs (eye, tongue, nose, ears, and skin) of humans. The robot control subsystem has been likened to the nervous system, the actuation subsystem to the muscular system, and the power subsystem to the cardiovascular system. This highlights the similarities between robots and humans and can be extended to other living things like dogs and birds.

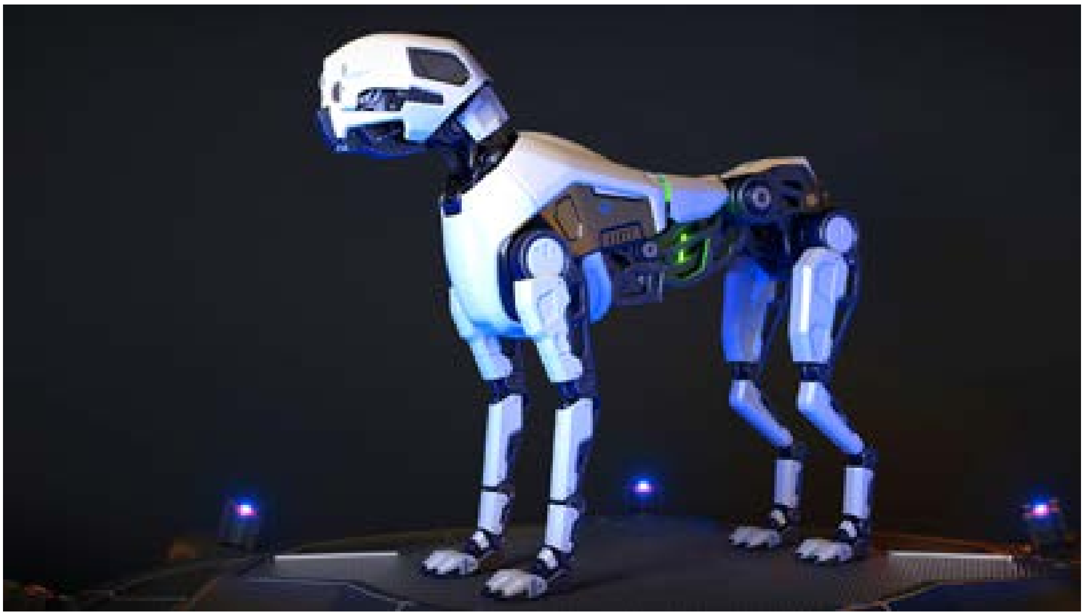


Fig. 3.1: Nature-inspired robotic design.

The similarities between robotic designs and living organisms exist because roboticists and robotic engineers often draw inspiration from nature, leading to the creation of robots and their components in a way that mimics biological systems.

The following points are examples of these nature-inspired similarities found in robots:

a. Sensing Subsystem: humans use sensory organs to see, feel, hear and smell. Robots use sensors to do the same thing. For example, a robot's vision system, which uses cameras and image sensors, is inspired by the human eye. Similarly, touch sensors on a robot's surface can mimic the sense of touch in human skin.

b. Control Subsystem: The human brain processes information and sends signals through the nervous system to coordinate bodily functions, much like how the control subsystem in a robot uses algorithms and processors to manage its operations. Advanced robots can even use artificial intelligence to process information and make decisions.

c. Actuation Subsystem: Human muscles enable movement and give strength, while robotic actuators perform similar functions. For instance, hydraulic or pneumatic actuators can mimic the contraction and relaxation of muscles, allowing robots to move and lift objects.

d. Power Subsystem: The human heart is the power system of the body, which can be likened to how a robot's power subsystem provides energy to drive its components. Batteries or fuel cells supply the necessary power for a robot to function.

Nature-Inspired Sensors

Below is a list of sensors used by robots that have been inspired by nature:

1. Cameras and Colour sensors

Fig. 3.2: Photo sensors. Image source: www.sick.com

The human eye sees different shapes and colours. Similarly, robots use cameras and colour sensors to recognise shapes and colours. These sensors help robots identify objects and navigate.

2. Odour sensors

Similar to how humans and animals use their noses to detect odours, robots equipped with odour sensors can detect and identify various smells. This is useful in applications such as detecting gas leaks, monitoring air quality, and even identifying spoiled food.

3. Audio sensors

Like the human ear, which detects sound waves, robots use audio sensors like microphones to pick up sounds. These sensors enable robots to understand spoken commands, detect alarms, and interact with humans through voice recognition.

4. Ultrasonic/Infrared proximity sensors

Robots use ultrasonic and infrared proximity sensors to measure distances and detect obstacles. Dolphins, whales, and bats use echolocation or sonar in a similar mechanism to detect objects. These sensors help robots avoid collisions and navigate complex environments.

5. Compound eye sensors

Robots with artificial compound-eye sensors can achieve wide-angle vision and detect movement just like the compound eyes of insects, which provide wide-angle vision and detect motion. This is particularly useful for robots that monitor large areas or track fast-moving objects.

6. Tactile sensors

Some robots are equipped with tactile sensors to enable them to sense physical contact and pressure. Similarly, rodents and cats also use their whiskers to detect vibrations, pressure, and touch. These sensors enable robots to handle delicate objects, detect surfaces, and interact with their environment through touch.

7. Thermoreceptors

Robots equipped with thermal sensors or thermoreceptors can detect temperature changes. This is useful for monitoring industrial processes, detecting heat leaks, and conducting search-and-rescue operations in low-visibility conditions. This mechanism is similar to how pit vipers and some insects detect infrared radiation emitted by warm-blooded prey or environmental heat sources.

Nature-Inspired Actuators

Nature-inspired actuators are devices that mimic the movement mechanisms found in living organisms. These actuators enable robots to perform flexible, precise, and efficient motions by drawing inspiration from biological systems. Here are some key examples of nature-inspired actuators.

1. Muscle-like actuators

Actuators are designed to mimic the function of biological muscles, contracting and relaxing in response to electrical signals. In the same way, biological muscles found in animals, including humans, contract and relax in response to electrical signals from the nervous system, allowing them to move their limbs and perform various actions.

Robots use muscle-like actuators to perform flexible and precise motions. These actuators allow robots to mimic human-like movements, making them useful in applications such as prosthetics, robotic surgery, and humanoid robots.

2. Pneumatic actuators

Pneumatic actuators use compressed air or gas that generate mechanical motion, similar to the movement mechanisms in certain animals, such as arthropods, insects, and spiders, which rely on air pressure for movement. These actuators provide robots with lightweight and efficient actuation. They are commonly used in industrial robots, soft robotics, and applications requiring quick and lightweight movement.

Watch this video demonstration of pneumatic actuators,

What is a Pneumatic Actuator? | Types & Applications

3. Hydraulic actuators

Actuators that use fluid pressure to produce linear or rotary motion. Like how large mammals and reptiles use fluid pressure to move parts of their body, such as their jaws or tails. Robots use hydraulic actuators to produce linear or rotary motion using fluid pressure. These actuators are powerful and are used in applications requiring high force and precision, such as construction robots, robotic arms, and heavy-duty machinery.

4. Shape Memory Alloys (SMAs)

These are a unique class of materials or alloys that can 'remember' their shape and can return to that shape after being bent. They practically change shape in response to temperature variations. This is similar to how certain plants exhibit shape-changing behaviours in response to environmental stimuli, such as temperature changes or pressure.

SMAs used in robots change shape in response to temperature variations, allowing robots to achieve self-reconfiguration or actuation without external power sources. These actuators are used in medical devices, aerospace applications, and robotics that require adaptive or self-healing capabilities.

Watch this video on SMA:

How a metal with a memory will shape our future on Mars

Nature-inspired Controllers

Biological brains found in humans and animals are responsible for processing information and making informed decisions. In a similar manner, robots employ processors, such as microcontrollers or microprocessors, to process data from one or more sensors as well as other (already stored) sources of data, analyse them, and generate appropriate output, which may be in the form of control signals for actuation.

You should now understand that the brains or 'controllers' of robots coordinate signals from 'sensors' and convert them to physical actions using 'actuators.

Activity 3.1

Observing surgical robots

Surgical robots are revolutionising the field of medicine by enabling minimally invasive procedures with high precision. These robots, such as the **da Vinci Surgical System**, use a combination of cameras, microprocessors, and actuators to assist surgeons in performing delicate operations.

a. *Sensors*: High-definition cameras and endoscopes provide surgeons with enhanced visualisation of the surgical site.

b. *Processors*: Advanced microprocessors interpret the surgeon's movements and translate them into precise robotic actions.

c. *Actuators*: Robotic arms equipped with surgical tools perform the actual surgery, minimising human error and reducing patient recovery time. Watch the following video for further explanation:

da Vinci® Robotic Surgical System

Activity 3.2

Exploring similarities between robots and living organisms

1. Observe a dog (local or foreign breeds) and a quadruped robot. Carefully watch their movements, body structure, and any other characteristics you notice.

   Examples of a quadruped robot and a drone are shown below:

   Dope Tech: Boston Dynamics Robot Dog!

   Sensors on Drones

2. Observe a bat and a drone. Carefully watch their movements, behaviours, and any other characteristics you notice. Your task is to identify and write down the similarities between these two entities.
   a. How do both the bat and the drone navigate through the air?
   b. What methods or systems do they use to avoid obstacles?
   c. How do both the dog and the quadruped robot move?
   d. What similarities can you find in their walking, running, and turning mechanisms?
   e. How do both a dog and a quadruped robot sense their environment?
3. Write down at least three (3) observed similarities between a dog and the quadruped robot.
4. Write down at least three (3) observed similarities between a bat and the drone.
5. Discuss your observations with other learners.

Activity 3.3

Sketch and label a robot dog

Materials needed

- pencil
- eraser
- exercise book

Steps:

1. Draw a picture of a robot dog in your exercise book.
2. Identify and label parts of the robot dog that are inspired by nature.
3. Specifically, look for sensors, actuators, and controllers in your sketch.
4. Once you have completed your sketch and labels, compare them with those of you of your classmates. Share what nature-inspired features you identified and how they might work in a robot dog.

PRINCIPLES UNDERLYING THE OPERATION OF ROBOTIC SENSORS

Sensors convert physical signals like light or sound into electrical signals that the robot can process. This conversion process is known as transduction. In the lessons that follow, you will discover why sensors produce electrical signals that can vary between sensors and vary over time. You will also learn why calibrating sensors is important to the function of robots. You will be guided to acquire knowledge of the scientific principles underlying the operation of sensors and the varying outputs of different linear sensors.

Visual Perception in Humans and Robots

Humans

1. **Light reception:** Light enters the eye through the cornea and is focused by the lens onto the retina.
2. **Image formation:** The retina, which contains photoreceptor cells (rods and cones), converts light into electrical signals.
3. **Colour and light intensity:** Cones are responsible for colour vision and function best in bright light, while rods detect light intensity and are used in low-light conditions.
4. **Signal transmission**: The optic nerve transmits these electrical signals to the brain.

5. **Processing:** The brain's visual cortex processes the signals to form images, enabling us to recognise shapes, colours, and movements.

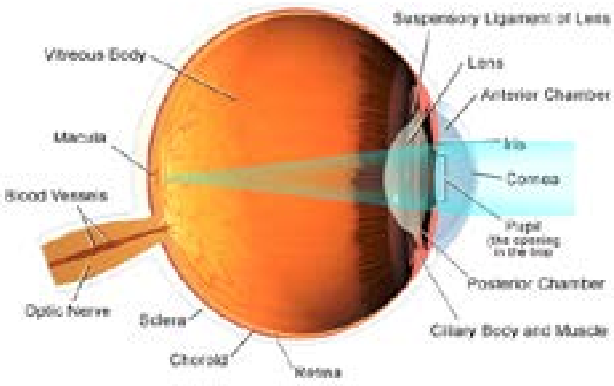


Fig. 3.3: The human eye

Robots

Robotic visual perception is the process by which machines interpret their environment using digital sensors and algorithms. Instead of biological eyes, robots use cameras to capture light, which is then translated into electronic signals by image sensors.

These electronic signals undergo computational analysis through complex algorithms, allowing robots to extract meaningful information from captured images. Tasks like edge detection, pattern recognition, and object classification help robots make sense of visual data.

Despite advancements in artificial intelligence and deep learning, robotic visual perception still relies heavily on computational power and sophisticated algorithms. While robots can learn and adapt over time, they lack the innate intuition and contextual understanding inherent in human vision.

Robotic visual perception involves a series of steps (as in the case of humans) that allow robots to capture, interpret and interact with their surroundings.

These are the steps robots use to see (or visualise) things:

1. Robots use cameras to capture light from their environment. These cameras function like the eyes of the robot, gathering visual information. Inside the camera, an image sensor (usually a CCD or CMOS sensor) converts the captured light into electronic signals. These sensors work similarly to the human retina.
2. The image sensor translates light into digital data as pixels. Each pixel represents a small part of the image. The robot uses various algorithms to analyse this digital data. *Key tasks include:*
    a. Edge Detection: Identifying the boundaries of objects within the image.
    b. Pattern Recognition: Recognising specific shapes, patterns, or features.
    c. Object Classification: Categorising objects based on learned models.

3. The processing unit in the robot acts as the brain, and it interprets the analysed data to understand the surroundings. Based on this interpreted data, the robot decides how to respond or act.
4. In complex robots and advanced robotics, a technique known as machine learning is used to improve the robot's perception over time. This allows the robots to identify new patterns and adapt to changing environments.
5. Finally, robots often use feedback from their actions to refine their perception and decision-making processes. This feedback loop helps in improving accuracy and performance over time.

Auditory Perception in Humans and Robotics

Sound travels as vibrations in the air, like ripples on a pond. In humans, the outer ear acts like a funnel, to catch these waves and direct them into our ear canal.

The eardrum at the end of the canal vibrates along with the sound waves. These vibrations travel through tiny bones in the middle ear, which act like a signal booster. The vibrations reach the cochlea, a snail-shaped structure filled with fluid and hair cells. Different parts of the cochlea respond to different sound frequencies, like high notes or low rumbles. When the vibrations activate hair cells, they send electrical signals up the auditory nerve to the brain.

Finally, the human brain interprets these signals! It figures out things like how loud the sound is (volume), how high or low it is (pitch), and even where the sound is coming from.

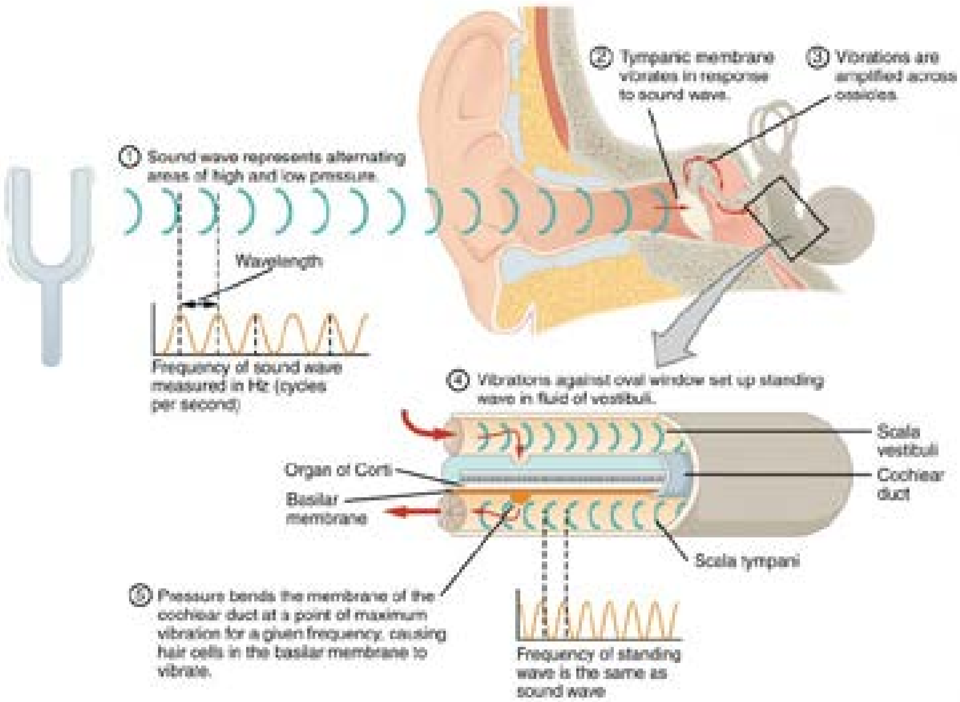


Fig. 3.4: Auditory system of the human ear

In robots, microphones are used to pick up sounds, just like human ears. These microphones convert sound waves into electrical signals the robot can understand. The robot then uses a software algorithm to analyse these electrical signals. This software is like the brain figuring out what the sounds mean.

Robots can be programmed to recognise different things from sounds, like:

a. Identify sounds, (i.e. is it a voice, a beep, or maybe crashing objects?)

b. Locate sounds (where is the sound coming from? Imagine a robot finding a lost puppy by following its bark).

Touch Sensing

Fig. 3.5: Robotic hand using touch sensing to pick up an egg.

Touch sensing refers to the ability of a device or system to detect physical contact or pressure. In the context of robotics or technology, touch sensing involves using sensors or mechanisms to detect when an object or surface is touched or pressed. These sensors can measure various aspects of touch, such as pressure, force, or texture, and convert this physical interaction into electrical signals that can be processed by the system.

Robots incorporate touch sensors that detect pressure, force, and texture. These sensors can use different technologies like capacitive sensing or resistive sensing. By using touch sensors, robots can feel objects, understand different surfaces, and complete tasks that need precise handling. The scientific idea behind touch sensing involves changing mechanical stimuli (like touch) into electrical signals and understanding these signals to know about the object being touched.

Spatial Sensing

Spatial sensing involves using sensors or technologies to gather information about the surroundings, including the presence of objects, distances to obstacles, and spatial relationships between different elements. Robots utilise environmental sensors such as proximity sensors, range finders, and infrared sensors to understand their surroundings.

Proximity sensors find out if objects are nearby or not. Rangefinders measure distances to objects using methods like ultrasonic waves or laser beams. Infrared sensors detect infrared radiation from objects to know their temperature or proximity. These sensors help robots avoid obstacles, move around safely, and interact with the environment.

Sensor Calibration

Sensor calibration is an adjustment or set of adjustments performed on a sensor or instrument to make that instrument function as accurately or as error-free as possible.

Imagine you are preparing boiled rice for your family. The recipe calls for a specific amount of water, but the scale on your measuring cup has become worn and difficult to read over time. This could lead to dry and undercooked rice!

Sensor calibration is like fixing that measuring cup – if the sensor reading is incorrect, then the robot will not function correctly.

Calibration is checking a sensor's accuracy and making adjustments if needed. It is like double-checking your measuring cup with a known amount of water (like 1 litre) to see if it is showing the correct quantity.

Precision, resolution, linearity and speed are qualities that make a **good sensor**.

1. Precision

Imagine you're weighing yourself on a scale every morning. Precision refers to how consistent the scale's readings are for your weight. If the scale is highly precise, it will always show the same weight for your morning weigh-ins, even if there are tiny fluctuations in your actual weight. Sensor precision can be affected by various factors, including external electrical interference or changes in operating temperature.

2. Resolution

This concept focuses on the smallest change a sensor can reliably detect in the quantity it is measuring. Applying the principle of resolution to measuring with a ruler will give you an idea of what this means. The ruler's resolution, or smallest scale might be in millimetres. This means the ruler can measure 50 millimetres and 5 millimetres, but it will not be able to measure accurately 50.5 millimetres.

3. Linearity

A sensor's output should directly reflect the measured quantity in a proportional way. Linearity describes how closely the sensor's output follows a straight line when plotted against the actual input value. A perfectly linear sensor makes calculations and calibration much easier because you don't need to account for any curves or deviations in the response. Imagine a temperature sensor where a one-degree increase in actual temperature results in a consistent one-unit increase in the sensor's output. That is a linear relationship.

4. Speed

This refers to how quickly a sensor can take a measurement and produce a reading. In some applications, speed is crucial. For instance, in a car's airbag system, a fast-responding sensor is essential to detect a collision rapidly and deploy the airbags before impact.

Why do sensors need calibration?

Sensors need calibration to provide accurate and reliable measurements. To achieve the best possible accuracy, a sensor should be calibrated in the system where it will be used.

Sensors need calibration because:

1. Manufacturing variations during the production of sensors mean that even two sensors from the same manufacturer production run may yield slightly different readings.
2. During transportation and even in assembling a robot, sensors are usually subject to heat, cold, shock, atmospheric pressure and differences in humidity. These can cause changes in the sensor's response when the robot comes to be used.
3. Differences in sensor design mean that different sensors may respond differently in similar conditions.
4. As sensors age, their response will change over time, and they may need periodic recalibration or replacement.
5. The sensor is only one component in the measurement system and must be matched to the other components.

How to calibrate sensors

There are two (2) key things that need to be determined when calibrating sensors. These are ***The standard reference*** and ***The `characteristic curve of the sensor***

1. The standard reference

This is a known value, which is compared to the value of any sensor. Highly accurate equipment is used to compare the output of sensors with standard reference values. Equipment used to calibrate sensors uses international **standard physical references**.

Accurate rulers or metre sticks can be used to verify distances measured by laser rangefinders or ultrasonic sensors. Similarly, boiling water at sea level (100°C) or an ice-water bath temperature (the water's "Triple Point" at 0.01°C at sea level) can serve as standard references for calibrating temperature sensors. Even common phenomena like Earth's gravity, which is a constant 1G on the surface, can be used to calibrate accelerometers.

2. The characteristic curve of the sensor

Each sensor has a unique "fingerprint" called its characteristic curve. This curve shows how the sensor's output changes as the input value increases or decreases. Ideally, we want the sensor's response to be perfectly proportional to the input (a straight line). Calibration helps us adjust the sensor's behaviour to match this ideal, straight-line response. The best way to do this depends on the specific shape of the sensor's characteristic curve, like the ones shown for different types of thermocouples (temperature sensor) in the figure below.

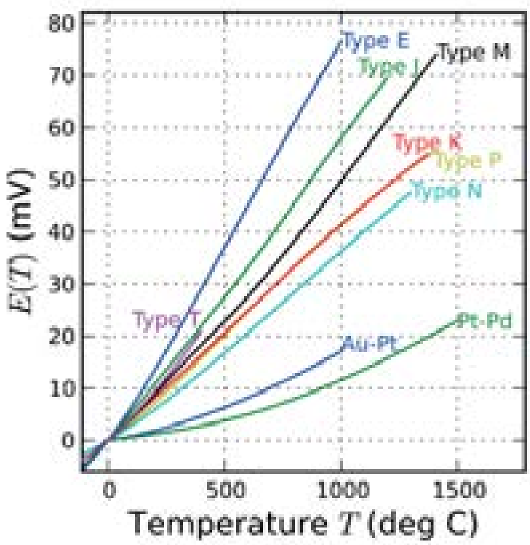


Fig. 3.6: Curves of different types of thermocouples

Methods for Calibrating Sensors

The three methods will look are:

1. One-Point Calibration
2. Two-Point Calibration
3. Multiple-Point Curve Fitting

One point calibration

One-point sensor calibration is a process of calibrating a sensor using a single known reference value. This method assumes that the sensor's response is linear across its range, so you only need to adjust the sensor reading to match the known reference at one point. It is commonly used when the sensor is expected to operate within a narrow range or when high precision is not required. Calibrating a temperature sensor against a known point like boiling point is an example of one-point calibration. If your ***sensor temperature measurement*** shows a small difference from your known reference point, this is called the calibration ***offset.*** In the graph, Figure 3.7, the actual response curve runs parallel to the ideal response curve.

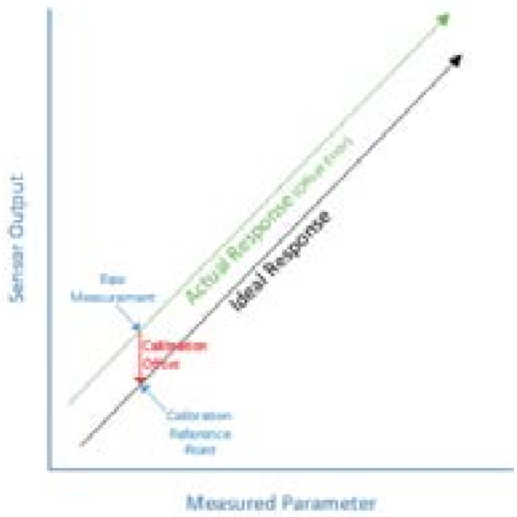


Fig. 3.7: One-point calibration offset

How to perform a one-point calibration:

To perform a one-point calibration:

1. Measure with your sensor.
2. Compare that measurement with your reference standard.
3. Subtract the sensor reading from the reference reading to get the offset.
4. In your code, add the offset to every sensor reading to obtain the calibrated value.

Example: Imagine that you have a competition robot that needs to position itself exactly 6 inches from a goal post in preparation for scoring, and you have an ultrasonic rangefinder for your distance sensor, as shown in Fig. 3.8 below.

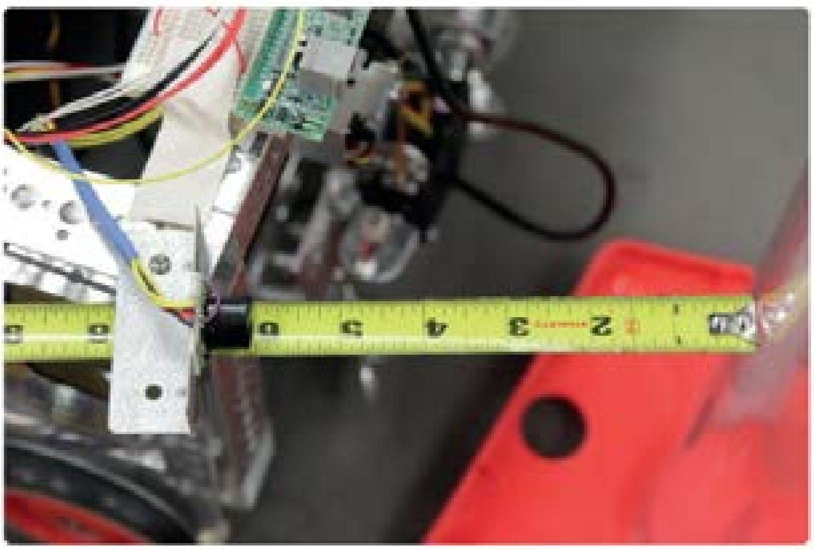


Fig. 3.8 One-point calibration

Since you only require maximum accuracy at one distance, a one-point calibration is a simple and effective solution. To perform a one-point calibration in this situation:

a. Using a measuring tape as your reference standard, position the robot exactly 6 inches from the goal post.
b. If you take a reading with your sensor and it says 6.3 inches, then you have -0.3 inches offset.
c. Now edit your code to subtract 0.3 inches from every reading. Since this is known to be a linear sensor, it will be pretty accurate over most of its range.

With this calibration done, you know with great confidence that it will be spot-on at the critical distance of 6 inches.

Activity 3.4

Materials needed

Your teacher will provide the following:

- A variety of sensors (if available): light sensor, ultrasonic sensor, temperature sensor (dummies are okay too!)
- Paper and pens

Steps:

1. Watch this short video clip. It is about automation on farms:
   The farming robots that will feed the world | Hard Reset
2. While you watch the video make some notes on the different ways robots and automation help in farming.

Activity 3.5

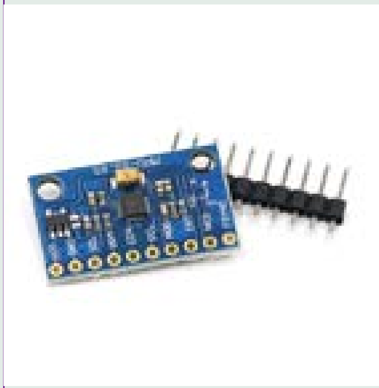
A pressure sensor	A proximity sensor	A gyroscope sensor
		
image source: www.eastsensors.com	Image source: www.componentstree.com	Image source: www.componentstree.com

Fig. 3.9

These pictures are to help you complete Activities 3.5 and 3.6. (A gyroscope is a sensor which is used to stabilise a robot, helping it drive in a straight line, making accurate turns).

Steps:

1. *Sensor Detectives:*
   a. Examine the provided sensors and pictures and note down any particular features or components you recognise, for example, resistors, processors, and diodes.
   b. Can you identify what each sensor might measure based on its appearance?
   c. What role does each sensor play in a robot's world?
   d. How does a light sensor help a robot navigate?
   e. How can an ultrasonic sensor prevent collisions?
   f. Think of real-life robots in Ghana, like agricultural bots or delivery droids. Describe which sensors could be used in these robots and what their purpose would be.
2. *Science of the Senses:* Working on your own, use books or the internet to find out the principles behind the workings of the following sensors:
   a. **Light Sensors:** How do they detect light and dark?
   b. **Ultrasonic Sensors:** How do they use sound waves to measure distance?
   c. **Temperature Sensors:** How do they convert heat into electrical signals?
3. *Calibration Check-Up:* Imagine a robot is programmed to follow a straight line drawn on the ground but instead zigzags across it. State clearly what you

think the problem is. What procedure would you follow to make the robot follow a straight line?

NB: This is where calibration comes in! You should have an idea from the information above as to why sensor calibration is essential for robots. It is like giving your robot a check-up to ensure its sensors are providing accurate information for smooth operation.

INTRODUCTION TO LINEAR SENSORS: VARIATIONS IN SENSOR OUTPUTS

Linear position sensors are used to find a position or a change in position in a straight path. They have many different applications in robotics and industrial settings. Object detection is one of the more common uses for linear position sensors in robotics. They can be used either as proximity sensors or as distance sensors.

Types of Linear Sensors

Potentiometer

Fig. 3.10: Potentiometer (Courtesy *Evans-Amos, 2019)*

Potentiometers are variable resistors with a sliding or rotating contact that moves along a resistive element. As the contact position changes, the resistance between the two ends of the element varies linearly, producing an output voltage or resistance proportional to the displacement.

Linear Variable Differential Transformers (LVDTs)

A Linear Variable Differential Transformer, also known as a Linear Variable Displacement Transformer, is a type of linear sensor that uses the principles of electromagnetism to measure very precise changes in position or displacement along a straight line.

LVDTs are transducers. They generate an output voltage that is proportional to the displacement of a movable core within a transformer assembly. They are highly accurate and used for precise displacement measurements (position along a given direction).

Linear Hall Effect Sensors

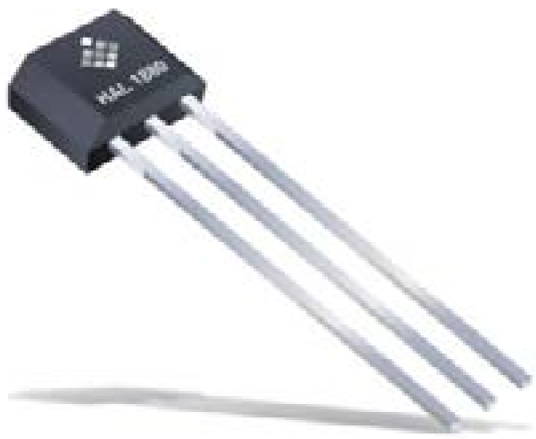


Fig. 3.11: Linear Hall effect sensor

A Linear Hall effect sensor is a type of linear sensor that uses the Hall effect (a voltage across an electrical conductor) to measure displacement or movement along a straight line. The sensor measures the strength of the magnetic field to determine the position or displacement of the magnet or a magnetic object. It then produces a voltage output that is linearly related to the magnetic field.

Factors that Influence the Variation in Linear Sensor Output

1. Temperature, humidity, and other environmental factors can impact the performance of linear sensors. For instance, temperature changes might affect the resistance or magnetic properties of the sensor materials, leading to variations in the output.
2. The accuracy of sensor calibration plays a significant role in determining the reliability of the sensor's output. Poor calibration can introduce errors and discrepancies in the measurements.
3. The linearity of a sensor refers to how closely its output follows a straight-line relationship with the input. Some sensors may exhibit non-linearity, resulting in output variations.
4. In some cases, the mechanical components of linear sensors, such as sliding contacts in potentiometers, can experience wear and tear over time. This can lead to inconsistencies in the sensor's output.
5. Some linear sensors are sensitive to variations in the supply voltage, which can affect their output readings.

Activity 3.6

Observing and Describing Sensors

Materials needed

- provided sensors
- pictures of additional sensors
- pencil/pen
- exercise book

Steps:

1. Your teacher will provide you with sensors. You can additionally search online for additional pictures of sensors. Observe these sensors and describe each of them.
2. Identify what each sensor measures and document why each sensor is important for a robot.
3. Identify and document real-world examples of how these sensors are used in robots.
4. Tabulate your findings:
   a. Write the name of the sensor.
   b. Provide a brief description of what the sensor looks like and its key features.
   c. Specify what the sensor measures (e.g., distance, light, temperature).
   d. Explain why this sensor is crucial for the functioning of a robot.
   e. Give examples of robots or applications where this sensor is used.

Example table:

Sensor Name	Description	Measurement Type	Importance to a Robot	Real-world Example
IR sensor	Small sensor that emits and detects infrared light.	Distance/ proximity	Helps robots avoid obstacles and navigate safely.	Used in autonomous vacuum cleaners to detect objects.

Activity 3.7

Comparing potentiometer outputs

Materials needed

Your teacher will provide the following:

- linear sensors (potentiometer)

- a microcontroller with data recording and display capabilities (e.g., Arduino with computer)
- breadboard
- connecting wires or jumper wires (male-to-male pin)
- ruler
- recording sheet or computer software for data collection

Steps: *Procedure for Sensor Setup*

Step 1. Connect the potentiometer to the microcontroller following the instructions provided below:

a. Insert the potentiometer with one leg in each of two separate rows.
b. Connect a red jumper wire from one outer leg to the Arduino's 5V rail (positive row).
c. Connect a black jumper wire from the other outer leg to the Arduino's GND rail (ground row).
d. Connect another jumper wire (any colour) from the centre pin of the potentiometer to an analogue pin (e.g., A0) on the Arduino.

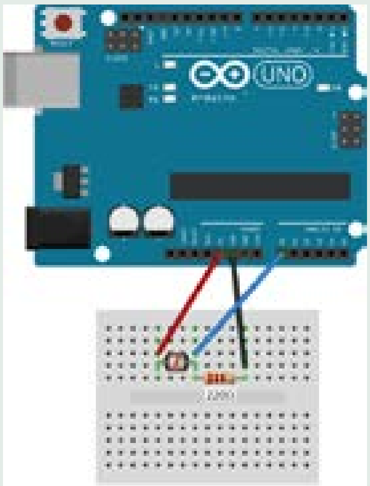


Fig. 3.12 Example Arduino wiring

Step 2. Use the ruler to track the position of the contact on the potentiometer. Mark a starting position (e.g., 0 cm) on the ruler.

Step 3. Record the initial potentiometer reading at the starting position.

Step 4. Gradually move the sliding contact along the potentiometer in small increments (e.g., 1 cm).

Step 5. Record the corresponding voltage output from the potentiometer for each new position.

NB: Repeat this process several times to gather multiple sets of data to plot a graph.

Step 6: Organise the reading and plot a graph:

a. Organise your collected data in a table or spreadsheet.

b. Plot the potentiometer output voltage (y-axis) vs. the position (length) (x-axis) on a graph.

c. Does the output voltage increase or decrease as you move the sliding contact?

NB: How closely do the data points follow a straight line? This indicates the linearity of the potentiometer's response.

Step 7: Repeat the experiment by starting at the other end of the potentiometer's travel. Do you get the same results?

Evaluation and Discussion

1. How does the potentiometer's output voltage change with position?
2. Is the potentiometer's response linear?
3. What factors might influence the linearity of the potentiometer?
4. In what real-world applications might potentiometers be used? Consider the advantages and limitations of using a potentiometer as a position sensor.

Running the Experiment

1. Connect your Arduino board to a computer and upload the code to your Arduino board.
2. Open the Arduino IDE serial monitor (Tools > Serial Monitor).
3. As you turn the knob of the potentiometer, you should see the voltage reading change on the serial monitor, reflecting the position of the knob.

Sample C++ Code:

\<CODE FONT/STYLE>

```
// Define the analogue input pin connected to the potentiometer
const int potPin = A0;

void setup() {
 // Start serial communication for displaying data
 Serial.begin(9600);
}

void loop() {
 // Read analog value from the potentiometer (0-1023)
 int sensorValue = analogRead(potPin);

 // Convert the analog reading (0-1023) to voltage (0-5V)
 // You can adjust the scaling factor (5.0) based on your
potentiometer's resistance
 float voltage = sensorValue * (5.0 / 1023.0);

 // Print the voltage value to the serial monitor
 Serial.print("Potentiometer Voltage: ").
 Serial.println(voltage, 2); // Print with 2 decimal places

 delay(100); // Delay between readings (optional)
}
```

<CODE FONT/STYLE>/

Hints

- This code defines a constant "potPin" for the chosen analogue input pin.
- In "setup()", serial communication is started to display readings on your computer.
- In "loop()", the "analogRead(potPin)" function reads the raw analogue value from the potentiometer (0-1023).
- The value is then converted to a voltage (0-5V) by multiplying with a scaling factor (adjustable based on potentiometer resistance).
- Finally, the voltage is displayed to the serial monitor along with a label.

LINEAR SENSOR CALIBRATION FOR OPTIMAL PERFORMANCE IN ROBOTIC SYSTEMS

You have learnt from the previous lesson that sensors are one of the most essential parts of robotic systems. They are the tools robots use to measure physical quantities like distance, speed and temperature. Sometimes, sensors give us slightly different readings even when measuring the same thing. You also learned how to calibrate linear sensors using a single reading and a reference point, single-point calibration.

The difference between single- and two-point calibration is in the accuracy. A single-point calibration involves adjusting the measurement device to match a single known reference value. In contrast, a two-point calibration uses ***two known reference values*** to adjust the device at two points. The two-point method generally provides greater accuracy over a wider range of values because it can correct for more systematic errors than the single-point method.

Two-Point Calibration

When you draw a line, you only need two points to know its direction and where it starts. Two-point calibration does the same thing for your sensor. It takes two readings from your sensor, one at a low value and one at a high value and compares them to the actual values you know are correct, known as **references**. This helps to adjust the sensor to measure or read the right value and follow the right pattern as the values change in the range between the minimum and maximum.

When to Use a Two-point Calibration

Two-point calibration is used for sensors that measure **linear data changes**. This means the change in its readings is steady and proportional to the change in what it is measuring. It is like knowing that for every step you take, you move forward the same distance.

How to perform a Two-Point Calibration

1. Measure low and high:

You take two readings from a sensor measuring a low value on a scale (like the minimum distance) and another reading when it is measuring a high value on the same scale (like the maximum distance).

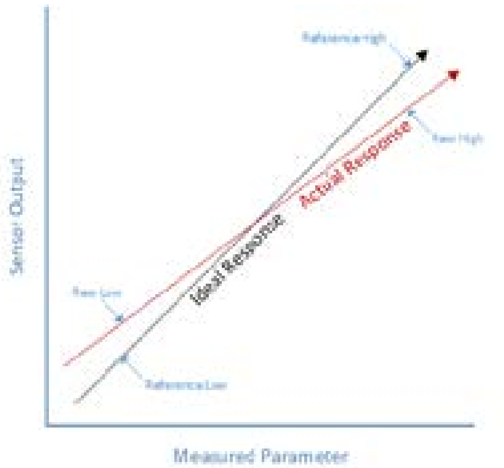


Fig. 3.13: Two-point calibration

2. Compare to the truth:

Then, you compare these readings to the actual, known values you are trying to measure. This shows how much our sensor is off and how much its "line" needs adjusting.

3. Adjust and conquer:

Finally, a mathematical formula compares the actual sensor reading with the expected output based on a known input. This ensures that it matches the true values at low and high points and that its readings follow the correct pattern in between.

In the experimental activities outlined below, we will now look at how we can calibrate a light sensor to see the world how we want it to.

Activity 3.8

Calibrating a light sensor (Experimental)

This activity is a sample demonstration of calibrating a light sensor. Your teacher will guide you through the steps.

The aim of this experiment is for you to adjust a light sensor by calibrating it to enable a more accurate light detection reading. The calibration will be useful when using the sensor in a robot that must navigate around objects that are very close together.

Materials needed

Your teacher will provide you with the following materials:

- Light sensor (Photoresistors like the one in your robotics kit or a standalone sensor)
- Arduino or similar microcontroller or simulation environment
- Resistor 220 Ohms
- Computer with Arduino IDE (or a similar coding environment)
- Breadboard and Jumper wires
- Darkroom or a light-proof box
- Bright lamp or flashlight
- Light meter (optional)
- White paper (optional)

Steps:

1. *Wiring the setup:*
   a. **For a Photoresistor**

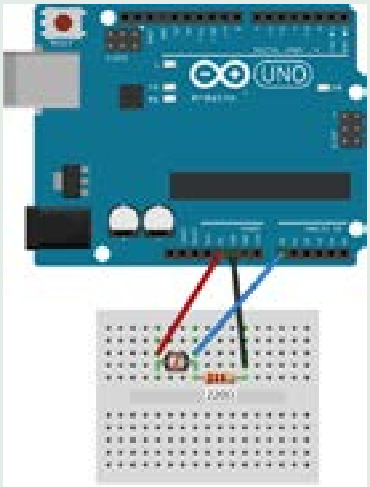


Fig. 3.14

- Connect one pin of the potentiometer to 5V on the Arduino microcontroller and the other pin to an analogue pin (like A0) and to one end of the resistor.
- Connect the other end of the resistor to GND.

   b. **When using other types of light sensors, other than a photoresistor,**

- Always follow the specific instructions for correct use that came with your sensor or look them up online. Your teacher can also help!

2. *Setting up the computer and the coding environment:*
   a. Open your Arduino IDE (or similar software).
   b. If your sensor needs a special library, install it (e.g., for the TSL2561).

c. Write a simple code (your teacher will provide you with the code) to read the raw values from the sensor. The code should display these values on your computer's Serial Monitor.
d. Take your sensor into a completely dark space (or put it in a lightproof box).
e. Open the Serial Monitor. You will see a number – this is your "RawLow" value, the reading your sensor gives in total darkness.
f. Shine your bright light source directly onto the sensor. (Use a white piece of paper if your sensor is too sensitive to direct light)
g. Watch the numbers change on the Serial Monitor. When they stabilise, that is your "RawHigh" value – the reading in bright light.

3. *Using the Calibration Formula:*
   a. **Decide Your Range**

      What numbers do you want your sensor to give as output? You can choose 0 for dark and 100 for bright, but you can pick any range! (0-255 is also common.)
   b. **Perform the calculations**
      i. **RawRange:** RawHigh - RawLow
      ii. **ReferenceRange:** ReferenceHigh - ReferenceLow (this is just 100 if you chose 0-100)

      The Formula

      CalibratedValue = (((RawValue - RawLow) * ReferenceRange) / RawRange) + ReferenceLow
4. *Test the sensor under different case scenarios:*
   a. Try different lighting conditions – shadows, sunlight, under a lamp.
   b. For each situation, record the "RawValue" from the Serial Monitor.
   c. Use your formula to calculate the "CalibratedValue."
   d. Do the calibrated values make sense? Do they match how bright it is?

You have calibrated your light sensor!

Now it is ready to help your robot navigate, detect obstacles, and make smart decisions based on light levels.

- Plot a graph of your raw readings versus the corrected values. What does it look like? Is it a straight line?
- If you have a robot, try using your calibrated light sensor to control its behaviour. For example, make it turn when it senses a change in light level.
- Explore how you might calibrate a sensor that does not follow a straight line. (This might be a bit tricky!)

Note: By calibrating your light sensor, you have taught it to "see" the world more accurately. Now you can use it for all sorts of cool robotics projects!

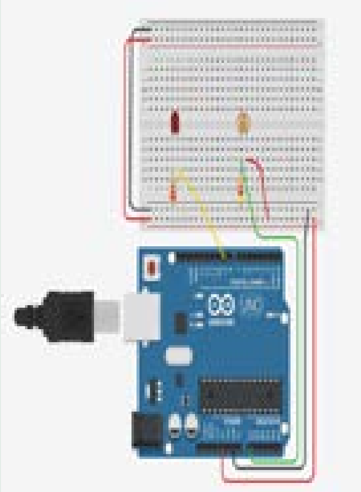


Fig. 3.15

Experimental Activity 3.9

The objective is to maximise the precision of the temperature sensor. Utilising two fundamental natural phenomena—the freezing and boiling of water—as your benchmarks, you will embark on a scientific journey.

Materials needed

- Temperature Sensor: (Thermistor, Thermocouple, LM75, DTH22)
- Microcontroller: Your Arduino (or compatible) board will be the brain for the sensor.
- Computer
- Breadboard and Jumper Wires
- Resistor (This helps the sensor work with your Arduino. The value depends on your thermistor – ask your facilitator!)
- Ice Water Bath
- Boiling Water Bath
- Safety Equipment (Heat-resistant gloves, goggles, and a lab coat)

Caution: Boiling water can cause burns! Always work with adult supervision and wear appropriate safety gear.

Steps:

1. *Circuit Setup:*
   a. **Thermistor:** If you are using this type, connect one leg to 5V on the Arduino, the other to an analogue pin (like A0), and to one leg of the resistor. Connect the other leg of the resistor to GND.
   b. **Other Temperature Sensors:** Follow the manufacturer's instructions or any diagrams you find online. Ask your teacher for help if needed.

2. *Code Preparation:*
   a. **Open Arduino IDE:** Start a new sketch (programme).
   b. **Include Libraries:** If your sensor needs a specific library, add the #include statement at the beginning.
   c. **Basic Code:** Write a simple code (or use an example) to read the sensor's raw values and print them to the Serial Monitor.

Example code (Thermistor):

\<CODE FONT/STYLE>

C++

```
const int temperaturePin = A0;
void setup() {
 Serial.begin(9600);
}
void loop() {
 int rawValue = analogRead(temperaturePin);
 Serial.println(rawValue);
 delay(100); // Read temperature every 100 milliseconds
}
```

<CODE FONT/STYLE>/

3. *Calibration Data Collection:*
   a. **Ice Water Bath ("RawLow")**
      i. Carefully immerse your sensor in the ice water bath, making sure the sensitive part is fully submerged.
      ii. Wait for the reading to stabilise on the Serial Monitor.
      iii. Record this value as your "RawLow." (It might be negative if your sensor goes below 0°C!)
   b. Boiling Water Bath ("RawHigh"):
      i. **With an adult's help**, carefully immerse the sensor in the boiling water.
      ii. Wait for the reading to stabilise on the Serial Monitor.
      iii. Record this value as your "RawHigh."
4. *Calibration Calculation:*
   a. **Reference Values:**
      i. We know water freezes at around 0.01°C and boils at 100°C at sea level.
      ii. So, our "ReferenceLow" is 0.01 and our "ReferenceHigh" is 100.
   b. **Calculate Range Values:**
      i. RawRange = RawHigh - RawLow

ii. ReferenceRange = ReferenceHigh - ReferenceLow (this is 99.99 in our case)

c. **Calibration Equation**

Corrected Temperature = (((RawValue - RawLow) * ReferenceRange) / RawRange) + ReferenceLow

5. *Test It Out:*
   a. Measure the temperature of different objects (a cup of water, your hand, the air, etc.).
   b. For each raw value, use your equation to calculate the corrected temperature.
   c. Do the corrected temperatures match the actual readings from the thermometer? Compare measured and calculated values from another thermometer if you can.

Congratulations!

You have successfully calibrated your temperature sensor! Now, your robot can accurately sense temperature changes and use that information to make smart decisions.

Multipoint Curve Fitting

In linear sensors, two-point calibrations tend to work concerning their use and calibrations. That is usually challenging with non-linear sensors. Nonlinear sensors do not follow linearity principles; hence, there is a need to find an optimum way of using non-linear sensors. Multipoint Curve Fitting helps determine the optimum operating points of non-linear sensors.

Curve Fitting

A typical illustration of curve fitting is seen in a roller coaster twist and turns. Some sensors tend to behave in a way that does not follow a specific pattern. Multi-point curve fitting is like finding a straight line between many random curves in a roller coaster movement that would help in predicting its movement. This is done by taking multiple readings of a sensor output at different points and finding an optimum connecting point among the many points.

When to Use It

Multi-point curve fitting is super helpful when dealing with sensors that have non-linear behaviour. Think of it as a way to tame those wild readings and make them behave predictably. One common example is thermocouples, which measure temperature but sometimes go a little haywire at extreme temperatures.

How It Works

1. **Gather the Clues:** You start by taking several readings from your sensor at different levels of what it is measuring (like temperature, pressure, light, and sound). This gives you clues about the shape of the curve.
2. **Connect the Dots:** Next, a mathematical formula is used to find the best curve that fits all your data points. This curve is like a map that shows you how the sensor's readings change along with the quantity it is measuring.
3. **Predict the Future:** Now that you have this 'map' or curve, you can use it to predict what the sensor will read at any point along the curve. It is like knowing where the roller coaster will be at any moment, even if you have not ridden that exact part of the track yet.

The Result: A sensor that we can rely on, even when it tends to be a little unpredictable! By using multi-point curve fitting, you can make sure your robot projects get accurate information from all kinds of sensors, whether they are linear or not.

Pro Tip: There are already pre-made curves for common sensors like thermocouples, so you might not even need to create your own! But if you are working with a custom sensor, this is where your maths skills will shine!

Activity 3.10

Constructing a Robot that can Follow a Line

When constructing a line-following robot that utilises a light sensor to detect the line, you will encounter raw sensor readings ranging from 20 (dark) to 80 (bright). To enhance the robot's accuracy in following the line, it is essential to calibrate these readings to a range from zero (off track) to 100 (centred on the line).

This calibration process enables the robot's sensor to interpret its environment more effectively. Lower calibrated values (close to 0) indicate the robot is off track, while higher values (up to 100) indicate it is centred on the line. This adjustment ensures the robot can clearly "see" and follow the line with precision, significantly improving its line-following performance.

Materials needed

- Light sensor
- Multimeter (or device to measure sensor output)
- Black surface (represents "off track")
- White surface with a black line (represents the actual line)

Steps:

1. Place the sensor completely off the line (on a black surface).
2. Measure the raw output voltage with your multimeter. Write this number down ("RawLow"). Think of it as the "off track" reading.

3. Now, put the sensor right in the middle of the black line.
4. Measure the raw voltage output again. Write this number down ("RawHigh"). This is the "centred on line" reading.
5. Use a simple formula to convert these raw readings into a more useful range (0-100).
6. A calibrated range of 0-100 gives a clear scale for programming control algorithms, making it easier to define thresholds for steering corrections. Just remember the RawLow and RawHigh values you measured and plug them into the formula

   Calibrated Output = (Raw Output - RawLow) / (RawHigh - RawLow) * 100

   a. Raw Output is the voltage you measure from the sensor at any point on the line.
   b. RawLow is the value you recorded in step 1 (represents "off track").
   c. 100 and 0: These are your desired reference values for "centred on line" and "off track," respectively.
7. Now test it out:
   a. Place the sensor at different spots on the line (not directly centred).
   b. Measure the raw voltage output (Raw Output) from the sensor at each position.
   c. Use the formula above, plugging in your Raw Output value, RawLow, and 100.
   d. This will give you the Calibrated Output, which should be a number between 0 (off track) and 100 (centred).

Review Questions 3.1

1. Imagine you are part of a team designing a new robot to help with household chores. You need to choose the appropriate sensors for different tasks. One task is to detect when the room lights are turned on or off, and another is to sense when the robot bumps into objects or people.
   a. State two (2) sensors you would choose for detecting room light changes and the sensor you would use to sense obstacles.
   b. Explain the differences between the two sensors mentioned in 1(a) in terms of their functions and applications.
2. You are an engineer tasked with explaining how a new rescue robot can navigate through debris to find and assist injured people after an earthquake. This robot needs to 'see' its environment, 'think' about the best path to take, and 'move' through obstacles.

   Describe how the robot's sensors, processors, and actuators work together similarly to how the human brain, senses, and moving parts (like muscles) function. Provide specific examples of each component's role in both the robot and the human body.

Review Question 3.2

1. Describe how a robot moves on its own (autonomously) in a given environment.
2. You have been tasked with designing a new home-cleaning robot! One of the most important features is the ability to avoid obstacles like furniture and pet toys. Unfortunately, your budget only allows you to include two linear sensors. Considering the different functionalities of various linear sensors, which two would you choose to equip your robot with for the most effective obstacle detection?
3. You are an engineer tasked with maintaining a state-of-the-art greenhouse for a research facility. The greenhouse relies on various sensors to monitor and optimise plant growth conditions. However, you have noticed some unexpected fluctuations in sensor readings, leading to inconsistencies in plant growth across different areas.
4. Your job is to identify two factors that might be influencing these variations and propose solutions to control them for more consistent and reliable sensor data. Map the following sensors to their respective scientific principles.

Sensors	Scientific Principle
Light sensor	Measuring light intensity
Temperature sensor	Measuring proximity
Location sensor	Measuring the voltage across the diode terminals
Ultrasonic sensor	Measuring and detecting the position of an object using a built-in GPS receiver

Review Questions 3.3

1. Two-point calibration is a method for fine-tuning a sensor's accuracy by taking readings at two known extremes within its measurement range. This calibration method is suitable for sensors with which characteristic?
2. A temperature sensor reads 50°C raw output. After a two-point calibration with ice water (0°C) and boiling water (100°C) as references, the calculated corrected value is 52°C. Explain how this correction improves the sensor's performance.
3. When designing a line-following robot that uses a light sensor to detect the line. The raw sensor readings range from 20 (dark) to 80 (bright). However, you want the calibrated output to range from 0 (off-track) to 100 (centred on the line).
   a. Follow the procedure for two-point calibration to convert the raw sensor readings to the desired calibrated output range (0-100).
   b. Explain how this calibration improves the robot's line-following performance.

Answers to Review Questions 3.1

1.

a. Light sensor and Ultrasonic Proximity sensor

b.

Light sensor	Ultrasonic Proximity sensor
A light sensor detects and measures the intensity or properties of light.	An ultrasonic proximity sensor detects the presence or distance of an object using sound waves (ultrasonic).
Light sensors are used to automatically control streetlights, motion-activated lights, cameras, and displays.	Object detection, collision avoidance, level sensing, and distance measurement.

2. In the rescue robot and the human body, sensors and sense organs gather information about the environment, respectively. For example, the robot may use cameras and infrared sensors to detect obstacles, similar to how human eyes detect objects. Processors in the robot and the human brain analyse this information to determine the best course of action. The robot's processor might use algorithms to map out a safe path, akin to the human brain processing visual cues to plan movements. Finally, actuators in the robot, such as motors or hydraulic systems, physically move the robot through obstacles, much like muscles in the human body propel movement.

Answers to Review Questions 3.2

1. The robot combines sensing, figuring out location, planning, and adapting to its surroundings to move autonomously.

   For example, sensors like tiny cameras or laser beams act like eyes, constantly feeding information about the environment. This information helps the robot understand where it is, like you finding yourself on a map. With this map and a goal (reaching a specific spot), the robot creates a plan for how to move. Finally, it translates that plan into commands for its wheels, just as when you steer your bike. Throughout its journey, the sensors keep sending updates, and the robot adjusts its path if needed.

2.
   - Ultrasonic sensors
   - Lidar (Light Detection and Ranging)
   - Light sensor
   - Potentiometer

3.
   Environmental factors like temperature:

   Place temperature-sensitive sensors in areas with minimal temperature fluctuations, away from direct sunlight or heating/cooling vents.

   Sensor degradation:

   Establish a routine for calibrating your sensors at regular intervals. This involves comparing the sensor's output to a known reference standard and adjusting its calibration parameters if necessary.

4.

Sensors	Scientific Principle
Light sensor	Measuring light intensity
Temperature sensor	Measuring the voltage across the diode terminals.
Location sensor	Measuring and detecting the position of an object using a built-in GPS receiver.
Ultrasonic sensor	Measuring proximity

Answer to Review Questions 3.3

1. Two-point calibration is suitable for sensors with a **linear response.**

   This means the change in the sensor's output is directly proportional to the change in the quantity it is measuring.

2.

   Offset Correction.

   The raw output of 50°C might not be entirely accurate. There could be an inherent bias in the sensor itself, causing it to consistently read a few degrees higher or lower than the actual temperature.

   Improved Accuracy Across Range.

   Two-point calibration does not only fix a single point. It establishes a more accurate relationship between the sensor's output (voltage) and the actual temperature across its entire operating range.

3.

a. The raw sensor reading, RawLow = 20 and RawHigh = 80

   The reference sensor readings, ReferenceLow = 0, RefereneHigh = 100

   Calculate the range:

   RangeRaw = RawHigh - RawLow

   RangeRaw = 80 - 20 = 60

   ReferenceRange = ReferenceHigh - ReferenceLow

   ReferenceRange = 100 - 0 = 100

   Calculate the parameters:

   The slope (m) = ReferenceRange / RangeRaw

   Slope (m) = 100/60 = 5/3

   The intercept (b) = RefenceLow - m x RawLow

   Intercept (b) = 0 - (5/3) x 20

   Intercept (b) = 100/3

   Calibration Formula:

   Use the formula to convert any raw sensor reading (R) to calibrated output (C)

   calibrated_value (C) = m × raw_value (R) + b

   Therefore,

   calibrated_value (C) = (5/3) × raw_value (R) + (100/3)

Hints

- **Define Calibration Points**

  Point 1: Sensor reading when fully off the line (darkest point) = 20

  Point 2: Sensor reading when directly on the line (brightest point) = 80

- **Determine Output Range**

  The desired output range is 0 to 100.

- **Calculate Calibration Parameters**

  Calculate the slope (m) of the line that maps raw sensor readings to calibrated output.

  Calculate the intercept (b) of the linear transformation.

- **The Linear Transformation Formula**

  Using the linear transformation formula, substitute the values

  calibrated_value (C) = (5/3) × raw_value (R) + (100/3)

b. Calibrating the sensor ensures that the robot's readings correspond accurately to the actual position relative to the line. This reduces errors in the detection of the line and also improves the precision of following the line. Calibration makes sensors consistent by reducing variability in sensor readings due to environmental factors (such as lighting changes). This consistency allows the robot to maintain steady performance across different conditions.

EXTENDED READING

- Watch a simple video demonstration of some basic electronic components. Here Biomimicry for better design | Andy Middleton | TEDxBedford
- Watch a simple video demonstration of some basic electronic components. Here Meet Spot, the robot dog that can run, hop and open doors | Marc Raibert
- Further reading about Actuators: Visit httpswww.realpars.com
- Robots application in aero-engine repairs. https://www.nottingham.ac.uk/utc-manuonwingtech/research/robotics-for-in-situ-repair/robotics-for-in-situ-repair.aspx
- How robots are changing the farming industry | CNBC How Robots Are Changing The Farming Industry | CNBC

REFERENCES

1. www.realpars.com | *Actuators and video demonstrations*
2. *Beig, F. (2023, September 14). Simple light sensor circuit. Circuits DIY. https://www.circuitsdiy.com/simple-light-sensor-circuit/*
3. *Calibrating Sensors* by Bill Earl | www.adafu.it
4. Bill Earl (2024). *Sensors Precision. (https://learn.adafruit.com/calibrating-sensors/why-calibrate)*
5. Bill Earl (2024). Multi-point-curve-fitting. (https://learn.adafruit.com/calibrating-sensors/multi-point-curve-fitting)
6. Bill Earl(2024).*Thermocouple characteristic curves* (https://learn.adafruit.com/calibratingsensors/multi-point-curve-fitting)

ACKNOWLEDGEMENTS

Ghana Education Service (GES)

(GAST)

List of Contributors

Name	Institution
Griffith Selorm Klogo	Kwame Nkrumah University of Science and Technology
Asare Boakye Ansah	Kumasi Technical University
Gershon Normenyo	Kwame Nkrumah University of Science and Technology
Nero Kofi Etornam Novor	Kwame Nkrumah University of Science and Technology
Samuel Quarm Olatunde	GES, Kumasi