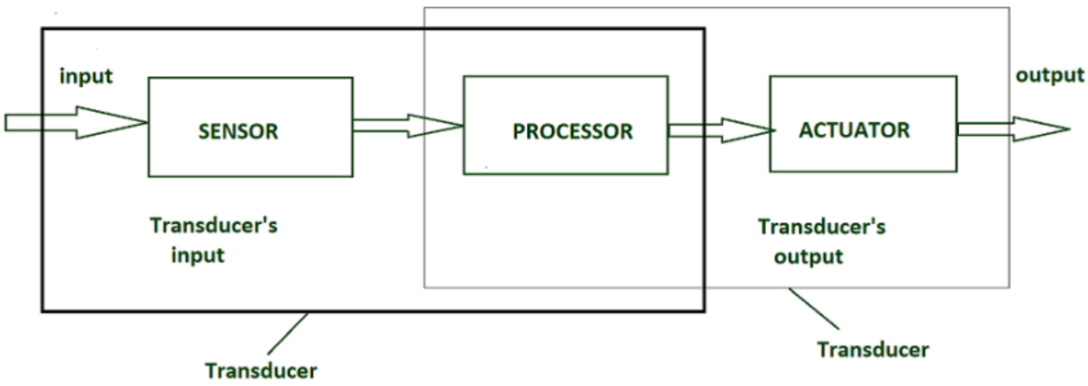
SENSORS

Sensors are the devices that can detect and response to changes in the environment. These changes can be in form of light, temperature, motion, moisture, or any other physical property. The sensor converts these physical changes into signal that can be measured. Sensors play an important role in IoT which will make an ecosystem for collecting, analysing, and processing data about a specific environment so that it can be monitored, managed, and controlled more easily and efficiently. Sensors bridge the gap between the physical world and the logical world.

A sensor is a part of transducer, where sensor detects or senses the physical quantity while transducer includes not just sensing element, but also circuitry needed to convert that sensed value into a usable signal giving electrical or physical output. Transducers are based on principle of conservation of energy. Sensors are an input stage of a transducer. For example, in temperature measurement, sensors like microphone, Diaphragm detects sound waves while transducer converts diaphragm vibrations to electrical signals. Output transducers are called Actuators, which convert electrical signals to Physical quantity.



In a system, physical quantity enters the system, which is sensed by sensors and converted into electrical signals which forms a transducer’ s input. Processor often amplifies, filters or converts (from analog to digital) the signal and actuator takes processed signal and produces a useful output action.

CLASSIFICATION OF SENSORS

1. Based on Power source:
    a. Active sensors: These sensors require external excitation or power source to operate. For example, a thermocouple which generates its own voltage. They need more power supply but usually give more accurate, linear and stronger signals.
    b. Passive sensors: They do not require an external power supply but instead generate response directly. They are often simpler and more reliable while the output can be small and need more amplification.
2. Based on Functioning principle:

a. Physical sensors: Measures physical quantities such as temperature, pressure and motion. The applications include, proximity sensors, temperature sensors, etc.
b. Chemical sensors: Detects chemical changes and converts them into electrical signals. Applications include Fire detection alarms, Chemical concentration in chemical plants, Pollutant detection, etc.
c. Biological sensors: Detects and measures biological entities or processes. Applications include, Glucose biosensors, Pathogen detection, DNA biosensors for genetic analysis, etc

3. Based on conversion phenomena
    a. Photoelectric: Changes light to electrical signals
    b. Thermoelectric: Changes temperature difference into electrical voltage
    c. Electrochemical: Changes chemical reactions to electrical signals
    d. Electromagnetic: Changes magnetic fields to electrical signals
    e. Thermoptic: Changes temperature changes to electrical signals
4. Based on Output Type:
    a. Analog signals: It produces continuous output signals which is used in form of voltage, current, or resistance, directly proportional to measured physical quantity. Examples include Thermistor used in refrigerators, weather stations for temperature, LDR in street lights for light, Pressure sensors in car tire pressure monitoring, etc.
    b. Digital signals: Provides output in form of discrete signals, internally converts measured analog into digital format. Examples include Digital temperature sensors used in IoT devices, weather monitoring, and Proximity sensors in automatic doors, etc.

TYPES OF SENSORS

1. PROXIMITY SENSORS

Proximity sensors include all sensors that perform non-contact detection in comparison to sensors that detect objects by physically contacting them, Proximity sensors convert information on the movement or presence of an object into an electrical signal.

According with the non-contact object detection method, there are five types of proximity sensor. They are,

1. Inductive Proximity Sensor: They are useful to detect the metallic object which is present next to their active side. This sensor operates under the electrical principal of inductance; in the presence of a coil which generates oscillating magnetic field, where a fluctuating current induces an electromotive force (EMF) in a target object. Sensing elements include Coil of wire and ferrite core which generates alternating electromagnetic field when an object enters. They have many industrial and robotic applications like conveyer belt and safety switches in robotic arms.

2. Optical Proximity Sensor: These include a light source, and a sensor that detects the light. These sensors detect objects directly in front of them by the detecting the sensor’s own transmitted light reflected from an object’s surface. Sensing elements include light source like LED or laser, Photodetectors, etc as they emit light and detects the reflection or interruption of the light beam to sense objects. Examples would be Elevator door sensor which prevents closing when someone is inside, Automatic soap dispensers, etc.

3. Capacitive Proximity Sensor: They can detect both metallic and non-metallic targets in powder, granulate, liquid, and solid form. The capacitive proximity sensors use the variance in the capacitance of the sensor to concluded that an object has been detected. Sensing element contains metal plates as electrodes. An example would be touchscreen on smartphone.

4. Magnetic Proximity Sensor: This sensor only detects the magnetic field(e.g. Permanent magnet) as it is based on mechanical principle. They sense the presence of a magnetic object, commonly referred to as the target. The target, characterized by its magnetic field, triggers the switching process; when it enters the detection range of the sensor. Sensing elements include ferromagnetic metal or semiconductor materials like silicon that respond to magnetic field. An example would be Fridge or door alarm sensor.

5. Ultrasonic proximity Sensor: They emit an ultrasonic pulse which is reflected by objects in its path and the reflected wave enters the sonic cone. They employ sound waves to detect objects, so colour and transparency do not affect them (though extreme textures might). Sensing material include Piezoelectric crystals, usually ceramics as they generate and receive ultrasonic waves. An example would be Automatic faucet, Robot vacuum cleaners, etc.

2. COLOUR SENSORS

The component used to detect colours is the Colour sensor. A colour sensor detects the colour of the material. This sensor usually detects colour in RBG scale. This sensor can categorize the colour as red, blue, or green. These sensors are also equipped with filters to reject the unwanted IR light and UV light. To detect the colour of material three main types of equipment are required.

A light source to illuminate the material surface, a surface whose colour must be detected and the receivers which can measure the reflected wavelengths. Colour sensors contain a white light emitter to illuminate the surface.
Three filters with wavelength sensitivities at 580nm, 540nm, 450nm to measure the wavelengths of red, green, and blue colours respectively. Based on the activation of these filters, the colour of the material is categorized.
A light to voltage converter is also present in the sensor. By comparing the voltages from red, green, and blue channels, the sensor can categorise the colour of the object. The sensor responds to colour by generating a voltage proportional to the detected colour.

Applications include sorting objects by colour on a conveyer belt, detecting coloured labels or packaging, Quality control in manufacturing, etc. A practical example of colour sensor’s application would include Candy sorting machines where candies are passed along conveyer belt, colour sensor shines light and detects its colour using red, green, and blue filters, and based on sensor reading machine diverts candies into different bins according to colour. This helps in speeding up the sorting process.

3. LDR SENSORS

A Light Dependent Resistor (LDR) is a type of passive electronic sensor used to detect light. It’s a type of optoelectronic sensor that is used for detecting light in the environment.

It’s made up of two conductors separated by an insulator which becomes more conducting when exposed to high levels of light intensity, forming a variable resistor in the circuit.

This allows it to measure the amount and brightness or darkness within its environment and provide information accordingly. They are typically used in automated light control systems, for dimming light according to environment without human intervention.

Further applications of LDR include motion detectors like burglary alarm security systems because they can detect if something passes through beamline quickly from dark-to-light conditions created. Thus they are ideal tools for sensing in both commercially and domestic level settings.

LDR also have low power requirements making them ideal for saving energy and such applications like solar cells, garden lightening system where high sensitivity allows precise illumination control even under tightly controlled situations. Their small size further increases flexibility as well as giving devices versatility across multiple different projects while being able to fit inside tight spaces.

Most home appliances and outdoor lighting systems are operated manually which not only makes them dangerous, but also wastes energy due to staff negligence or unforeseeable events when turning this electrical equipement ON and OFF.

LDR light sensor is a passive component that produces an electrical signal from light energy, whether in visible or infrared portions of the spectrum. Because they transform light energy to electricity, light sensors are more generally referred to as Photoelectric devices or Photo Sensors.

Working principle includes Photoconductivity theory which underlies the operation of this resister. It is nothing more than the fact that when light strikes its surface, the metarial's conductivity decreases and electrons in the device's valence band are stimulated to the conduction band. These incient photons must have energy larger than semiconductor metarial's band gap.

There are two types of LDR:

a. Intrinsic Photo Resistors: They are pure semiconductors made of germanium or silicon. The number o charge carriers increases because of the electrons being stimulated from the valence band to the conduction band when light strikes the LDR.
b. Extrinsic Photo resistors: The impurities added to these devices result in the creation of new energy bands above the valence band. There are electrons inside the bands. As a result, band gap is reduced, and less energy is needed to move them.

Advantages of LDR include their high sensitivity, easy use, simplicity and size, low cost, etc while disadvantages include limited spectral response, chemical reaction in stable materials, lack of responsivity, limitation with temperature changes, etc.

Smoke detector alarms, photoresistors, automatic lighting clock, etc are common applications of these sensors.

4. HALL EFFECT SENSORS

The hall effect sensor is a type of magnetic sensor which can be used for detecting the strength and direction of a magnetic field produced from a permanent magnet or an electromagnet with its output varying in proportion to the strength of the magnetic field being detected. Magnetic sensors convert magnetic or magnetically encoded information into electrical signals for processing by electronic circuits. They are devices which are activated by an external magnetic field. The output signal from a Hall effect sensor is the function of magnetic field density around the device. When the magnetic flux density around the sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage called the Hall Voltage, VH.

Hall Effect Sensors consist basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself. When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab. This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.

The Hall effect provides information regarding the type of magnetic pole and magnitude of the magnetic field. The output voltage, called the Hall voltage, (VH) of the basic Hall Element is directly proportional to the strength of the magnetic field passing through the semiconductor material (output $\propto$ H). This output voltage can be quite small, only a few microvolts even when subjected to strong magnetic fields so most commercially available Hall effect devices are manufactured with built-in DC amplifiers, logic switching circuits and voltage regulators to improve the sensors sensitivity, hysteresis and output voltage.

Hall Effect Sensors are available with either linear or digital outputs. The output signal for linear (analogue) sensors is taken directly from the output of the operational amplifier with the output voltage being directly proportional to the magnetic field passing through the Hall sensor.

Hall effect sensors are activated by a magnetic field and in many applications the device can be operated by a single permanent magnet attached to a moving shaft or device. There are many different types of magnet movements, such as "Head-on", "Sideways," "Push-pull" or "Push-push" etc sensing movements.
Applications include Laptop lid detection, Automobile wheel speed sensors, Tachometer, Electric vehicles, etc.

5. IMU SENSORS

The IMU sensor is an electronic device used to calculate and reports an exact force of body, angular rate as well as the direction of the body, which can be achieved by using a blend of 3 sensors like Gyroscope, Magnetometer, and Accelerometer. These sensors are normally used to plan aircraft including UAVs (unmanned aerial vehicles), between several others, & spacecraft, comprising landers and satellites. Modern developments permit the manufacture of IMU-based GPS devices.

An IMU sensor unit working can be done by noticing linear acceleration with the help of one or additional accelerometers & rotational rate can be detected by using one or additional gyroscopes. Some also contain a magnetometer which can be used as a heading reference. This sensor includes some usual configurations which include gyro, one accelerometer, and magnetometer for each axis used for each of the 3-vehicle axes like roll, yaw, and pitch.
It measures force, magnetic field, and angular rate. These sensors include a 3-axis accelerometer and gyroscope. So this would be measured as a 6-axis IMU sensor. These can also comprise an extra 3-axis magnetometer, so it can be considered like a 9-axis IMU.

Officially, the name IMU is just the sensor; however, these are frequently connected with the software like sensor fusion. This sensor merges data from numerous sensors to offer heading & orientation measures.

The applications of MIU sensor include GPS systems, track the motion within user electronics like cell phones, remotes of the video game, industries to support and calculate the location of equipment such as antennas, entertainment systems of flights and consumer airspace to add convenience within addition to contact in their remotes.

6. ENCODER SENSORS

Encoder sensors are a type of mechanical motion sensor that create a digital signal from a motion. It is an electro-mechanical device that provides users (commonly those in a motion control capacity) with information on position, velocity and direction. There are two main types of encoders: linear and rotary. Here, we look at encoder sensors in more depth.

Encoder sensors have become a widely used class of sensors where feedback information from a moving mechanical system is required. It is a device that can provide precise information on the speed, direction, and positioning of a piece of mechanical equipment. In recent years, encoders have become a lot more sensitive and tough with higher resolutions at a lower cost, and as a result are now widely used in many industries.

From an industry perspective, encoder sensors are used across the automotive, consumer electronics, medical, military, manufacturing and scientific instrument industry sectors. In terms of specific applications, encoder sensors can be found in printers, food processing, robotics, material handling, axis controllers, medical scanners, dispensing pumps, military-grade antennas, drilling machines and telescopes, to name but a few.

The Optical Encoders typically consist of a rotating and a stationary electronic circuit. The rotor is usually a metal, glass, or a plastic disc mounted on the encoder shaft. The disc has some kind of optical pattern, which is electronically decoded to generate position information.

The rotor disc in absolute optical encoder uses opaque and transparent segments arranged in a grey-code pattern. The stator has corresponding pairs of LEDs and photo-transistors arranged so that the LED light shines through the transparent sections of the rotor disc and received by photo-transistors on the other side. After the electronic signals are amplified and converted, they are then available for the evaluation of the position
With this encoder, the displacement is obtained by counting the number of times that transitions occur between logical values. This allows the transformation of

physical quantities by converting the angular displacement variations into electrical type signal output that is translated into logical values by suitable electronics.

The counting of the number of transitions that occur in the (reflective / opaque and non-reflective / transparent) disc sectors is related to the concept of resolution. The resolution may be defined as the smallest change in a quantity under measurement that causes a noticeable change in the corresponding outcome.

Information is obtained by simply counting the pulses. Therefore, it depends on the previous state and the value of the transition. Its biggest drawback consists in the need for defining a starting position reference: this information is lost whenever the system is powered down or is turned off.

7. ULTRASONIC SENSORS

Ultrasonic sensors are electronic devices that determine a target's distance. They work by emitting ultrasonic sound waves and converting those waves into electrical signals. Furthermore, ultrasonic travel at a faster rate than audible sounds. Ultrasonic sensor work involves sound waves to find the distance to an item. A transducer is also there to transmit and receive ultrasonic pulses. These pulses help to communicate information about an object within range.

Ultrasonic sensors operate by emitting sound waves at frequencies that are too high for humans to hear. The sensor's transducer serves as a microphone to receive and transmit ultrasonic sound. They also use a single transducer to send and receive pulses. Further, the sensor measures the total time taken to deliver and receive an ultrasonic pulse and calculates the target's distance.

The working principle of an ultrasonic sensor revolves around the emission and reception of high-frequency sound waves. These waves range from 20 kHz which is beyond the range of human hearing.

- **Emitting Sound Waves:** The ultrasonic sensor generates a burst of ultrasonic sound waves, usually in the range of 20 kHz to 65 kHz. These sound waves travel through the air towards the target object.
- **Bouncing Off Objects:** When the sound waves encounter an object in their path, they bounce off the surface of the object.
- **Measuring the Return Time:** The sensor measures the time it takes for the emitted sound waves to bounce back after hitting the object. This time interval is extremely short, typically measured in microseconds.
- **Calculating Distance:** The sensor figures out how far an object is by using the speed of sound in the air. It does this by multiplying the time it takes for sound waves to go to the object and then coming back by the speed of sound.
- **Output Data:** Last, the sensor provides this distance information as an output, which can be used in various applications, such as obstacle detection, object positioning, or navigation.

Ultrasonic sensors are used in many areas of engineering. In automation, robotics, and instrumentation, "no-contact" distance measuring is highly helpful. Further applications include Distance measurement, object detection, positioning and navigation, collision avoidance, etc.

8. TEMPERATURE SENSORS

A temperature sensor is a device, typically, a thermocouple or resistance temperature detector, that provides temperature measurement in a readable form through an electrical signal. A thermometer is the most basic form of a temperature meter that is used to measure the degree of hotness and coolness. Temperature meters are used in the geotechnical field to monitor concrete, structures, soil, water, bridges, etc. for structural changes in due to seasonal variations.

There are many types of temperature sensors, but, the most common way to categorize them is based on the mode of connection which includes, contact and non-contact temperature sensors.

Contact sensors include thermocouples and thermistors because they are in direct contact with the object they are to measure. Whereas, the non-contact temperature sensors measure the thermal radiation released by the heat source. Such temperature meters are often used in hazardous environments like nuclear power plants or thermal power plants.

The basic principle of working the temperature sensors is the voltage across the diode terminals. If the voltage increases, the temperature also rises, followed by a voltage drop between the transistor terminals of the base and emitter in a diode. The vibrating wire temperature meter is designed on the principle that dissimilar metals have a different linear coefficient of expansion with temperature variation.

It primarily consists of a magnetic, high tensile strength stretched wire, the two ends of which are fixed to any dissimilar metal in a manner that any change in temperature directly affects the tension in the wire and, thus, its natural frequency of vibration.

Temperature sensors are available in various types, shapes, and sizes. The two main types of temperature sensors are:

a. Contact Type Temperature Sensors: There are a few temperature meters that measure the degree of hotness or coolness in an object by being in direct contact with it. Such temperature sensors fall under the category of contact type. They can be used to detect solids, liquids, or gases over a wide range of temperatures.
b. Non-Contact Type Temperature Sensors: These types of temperature meters are not in direct contact with the object rather, they measure the degree of hotness or coolness through the radiation emitted by the heat source.

Applications include, thermostats, thermocouples, etc.

9. GAS SENSORS

Gas sensors use physical or chemical reactions to convert the concentration of various gases into electrical signals, and output values after calculation. Widely used to detect toxic and harmful gases and natural gas leaks.

The gas sensor is a device used to monitor the presence or level of gas in a stationary environment. Commonly used in coal mines, petroleum, chemical, municipal, medical, transportation, family, and so on. Gas sensors can measure the presence and concentration of combustible, flammable, toxic gases, or oxygen consumption.

According to different gas types: it can be divided into combustible gas sensors (catalytic combustion, infrared, thermal conductivity, semiconductor type), toxic gas sensors (electrochemical, metal-semiconductor, photoionization, flame ionization), Harmful gas sensors (infrared, ultraviolet, etc.), oxygen (paramagnetic, zirconia) and other types.

According to different sampling methods: it can be divided into diffusion sensors (the sensor is directly installed in the measured environment, and the measurement gas is in direct contact with the detection unit through natural diffusion), pumping sensors (through the suction pump, etc., the gas is sucked into the detection unit. According to whether the gas needs to be diluted, it is divided into complete inhalation and diluted inhalation).

According to the different detection principles: it can be divided into semiconductor gas sensor, electrochemical gas sensor, NDIR gas sensor, catalytic gas sensor, thermal conductivity gas sensor, magnetic gas sensor and so on.

Applications include semiconductor gas sensors, A semiconductor gas sensor is a device that uses a semiconductor element as a measuring unit. Its working principle is that the gas undergoes a redox reaction on the semiconductor, which causes the resistance value to change. As the gas passes through the measuring cell, it adsorbs on its surface and reacts. Gas levels are measured by causing a change in conductivity or potential characterized by carrier motion.

For example, when methane gas passes through the measuring cell, a reaction occurs that consumes oxygen. The pinned electrons are released, and the electrons are returned to the semiconductor, increasing the conductivity. When the electrons are fixed by oxygen, the resistance increases; when the methane reacts with oxygen, and the electrons return to the semiconductor, the resistance decreases. The resistance change is related to the presence, absence and amount of methane, and the methane content can be known by measuring the resistance change.

This is the most common gas sensor, widely used to detect combustible gas leak detection in homes and factories, and suitable for methane, liquefied gas, hydrogen, etc.

10. PRESSURE SENSORS

A pressure sensor is a device that senses and measures pressure. Pressure sensors allow for more specialized maintenance strategies, such as predictive maintenance. These devices collect real-time data on the conditions of equipment. Based on the available information, the sensors can predict and prepare for failure patterns.

Pressure sensors work by measuring a physical change that happens, as a reaction to pressure differences. After measuring these physical changes, the information is converted into electric signals. These signals can then be displayed as usable data that the team can then interpret.

For example, A strain gauge converts pressure to electrical signals.
The most common type of pressure sensor uses a strain gauge. It is a mechanical apparatus that allows small expansions and contractions, as pressure is applied or relieved. The sensor measures and calibrates the physical deformations to show how much pressure is put on a piece of equipment or tank. Then, it converts these changes into voltages or electric signals.

Electric signals are measured and recorded, as sensor produces an electrical signal, the device can record a pressure reading. These signals increase or decrease in intensity, depending on the pressure felt by the sensor. Depending on the signal frequency, pressure readings can be performed between very close time intervals.

CMMS receives an electric signal, electrical signals are now in the form of a pressure reading, in units such as pounds per square inch (psi) or Pascals (Pa). The sensors send out the readings, which are then received by your CMMS in real-time. With multiple sensors installed throughout various assets, a CMMS system acts as the central hub to keep track of the whole facility. CMMS providers can assist in ensuring the connectivity of all sensors. Upkeep CMMS, for example, offers options for the seamless integration of sensors and assets.

Pressure sensors have various applications which include Technology industry applications, Manufacturing applications like hydraulic and pneumatic systems, Energy conservation applications, etc.

11. VIBRATION SENSOR

A vibration sensor is a device that measures the amount and frequency of vibration in a given system, machine, or piece of equipment. Vibration sensors can be used to give maintenance teams insight into conditions within key assets that might lead to equipment failure, allowing them to predict the maintenance of the machinery, to reduce overall costs and increase the performance of the machinery. Their construction consists of a crystal of piezoelectric material to which is attached a seismic mass. When the crystal is stressed in tension or compression, it generates an electrical charge which is proportional to the acceleration level it is experiencing. Internal circuitry converts this signal into a voltage or current (4-20mA) output for data collectors or process control loops.

This robust device has no moving parts and offers long term stability and reliability. It has very wide frequency and dynamic ranges and signals can be integrated to give velocity and displacement values. Piezoresistive accelerometers consist of a seismic mass which is attached to a cantilever beam. The beam is deflected whilst experiencing 'g' forces and this movement is converted to an electrical signal by resistance changes in a semiconductor sensing element. Internal electronic circuitry provides amplification of the signal and temperature compensation. The frequency range of this device is lower than piezoelectric versions, but has the advantage of being able to monitor static or DC acceleration levels.

Vibration sensors play a vital role in the oil and gas industry by ensuring that the production machinery is operational and the downtime is minimized, thereby leading to a reduction in operating costs and an increase in productivity and monetary gains. These sensors help reduce unplanned outages and optimize machine performance. This, in turn, helps in reducing maintenance and repair costs. Vibration sensors designed for monitoring applications are used to monitor motors, critical pumps, fans, gearboxes, and compressors in the oil and gas industry.

The power industry is facing challenges owing to the continuously increasing demand for power and the requirement to reduce distribution losses. This has led power generation companies to offer continuous power supply at low costs and monitor their processes for any unwanted changes. Hence, vibration sensors play a crucial role in the power sector. Vibration sensors help in tracking rotor imbalances, aerodynamic asymmetry, surface roughness, and overall performance, as well as carry out offline and online measurements of stress and strain in energy and power industry.

The most common industrial applications of vibration sensors include rotating equipment such as pumps, motors, fans, compressors, gearboxes, gas turbines, bearings on conveyor systems, wind turbine gearboxes, wind turbine generators, dryer sections (pulp & paper), ovens & kilns (mineral processing), and hot rolling mills (metalworking).