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Technical Article Release

Robots Assume the Position with Sensors

By Bill Giovino

Today's robots perform functions as mundane as factory assembly, and as exciting as human-like machines on two legs from out of science fiction. Humanoid robots fascinate us – they can have lifelike faces, with movements that seem to mimic our own. Factory robots move with a curious grace and speed that can appear hypnotic. While these movements appear effortless to our own human eyes, it's easy to forget that it's all a simple feedback loop. Instructions are sent to an appendage which activates a motor that moves the appendage into position. But how does the system controller know that this position has been reached? By a network of sensors feeding back to the system controller.

Advances in MEMs sensor technology have greatly expanded the capacity of robots to achieve precision positioning. There are six types of useful sensing in robotics: tilt, rotation, acceleration, shock, vibration, and proximity.

Tilting Appendages

Tilt is useful for determining the position of a robotic arm. Tilt presents an interesting challenge in that it can be detected in a number of ways. It helps to first think of tilt as the change of direction of the force of gravity (*g*). Because gravity is really a type of acceleration, a low-*g* 3-axis accelerometer is one effective means of determining tilt. Anyone with a mobile phone is familiar with the function of low-*g* MEMs accelerometers as they are used to determine screen orientation when the mobile device is rotated.

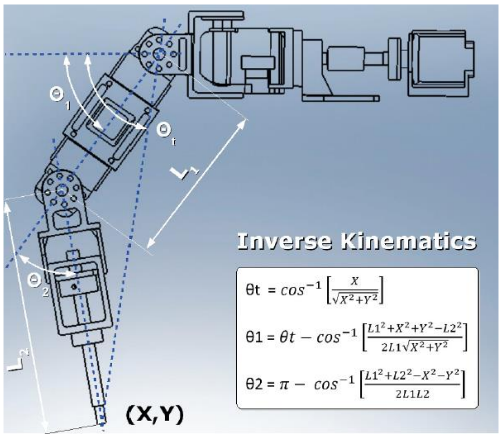

Figure 1*: Robot spider leg appendages* L_1 *and* L_2 *tilt along angles* θ_1 *and* θ_2*. Accelerometers in the appendages sense the tilt and feedback the position data to the inverse kinematics equation. Appendage* L_1 *also rotates along* θ_t *. (Source: Analog Devices)*

– continued –

The movement of a robotic spider leg as in ***Figure 1*** is determined by the use of complex inverse kinematics equations that decide the proper movement of the appendages by sending control signals to the motors. For such complex movement, feedback of each appendage's present position is critical for comparing the existing position with the desired position.

The ADXL345 3-Axis 13-bit Digital Accelerometer from Analog Devices (ADI) is used to measure the static acceleration of gravity in three-dimensional tilt-sensing applications. When using an accelerometer for tilt-sensing, the device is set to the lowest resolution. The ADXL345 supports ±2*g*, ±4*g*, ±8*g*, and ±16*g*. The lowest resolution ±2*g* setting is selected because Earth's gravity is only ±1*g*, so gravity sensing at ±2g resolution uses 12-bits, half the accelerometer's 13-bit range. While the higher full-scale scale ranges can also be used for tilt-sensing, because of the low-*g* forces being sensed even less of the full 13-bit range will go unused, resulting in greatly decreased accuracy.

For two-dimensional tilt sensing applications a low-*g* 2-axis accelerometer such as the ADI ADIS16003 ±1.7*g* 2-Axis Accelerometer can be used. A 2-axis accelerometer must be oriented so that the X-axis and Y-axis are parallel to the Earth's surface; in other words, at right angles to Earth's gravity. This allows the accelerometer to be used as a 2-axis tilt sensor supporting pitch and roll detection. Since the ADIS16003 supports a low 1.7*g*, when the accelerometer is perpendicular to gravity the output changes at a very sensitive 0.0175*g* per degree of tilt. At 45° the output changes at only 0.0122*g* per degree of tilt.

The accelerometer's output signal is converted to a number representing an acceleration varying between ±1*g*, allowing the tilt in degrees to be calculated as represented in **Formula 1**:

$$Pitch = \mathrm{ASIN}\left(A_X / 1\,g\right)$$

$$Roll = \mathrm{ASIN}\left(A_Y / 1\,g\right)$$

Formula 1*: Pitch and Roll calculations using a 2-axis accelerometer for Tilt sensing*

For the above formula,
A_X is the acceleration along the X-axis,
A_Y is the acceleration along the Y-axis.

It's important to note that while measuring tilt looks for only ±1*g*, incidents like a robotic arm hitting an object or coming to its end of travel can result in a signal much greater than ±1*g*.

Rotating Tools and Arms

Robot arms may rotate for various purposes. On an assembly line, rotating tools may include screwdrivers, drills, and clamps. While tilt is sensing linear rate motion, rotation is sensing angular rate motion. Rotation also differs from tilt in that it may take place without a detectable change in acceleration, making accelerometers useless for this application. For example if a 3-axis accelerometer is rotated around the z-axis which points to the Earth, while the x-axis and y-axis are parallel to the Earth, the Z-axis will continue to measure 1*g* while the X and Y axis will still measure 0g. In this situation, rotating the accelerometer along the Z-axis will result in no change in accelerometer readings. Instead, robots use MEMs gyroscopes, which are sensors specifically designed to sense rotation.

When a gyroscope sensor is rotated about its axis, a very small micromachined mass is moved by the Coriolis Effect to the outside of the sensor.

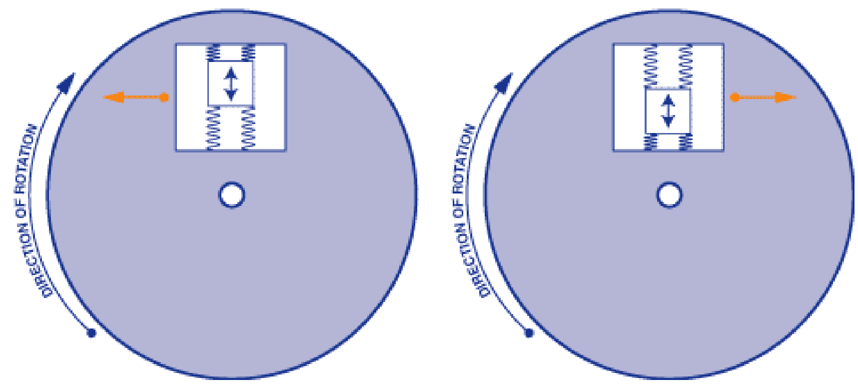

Figure 2*: Internal operation a MEMs gyroscope sensor (source: Analog Devices)*

The ADI iSensor MEMS Gyroscope Subsystems are designed to reliably detect and accurately measure the angular rate of rotation of an object. iSensor gyroscopes are rugged enough to detect rotation under the harsh environment of a robot under severe stress and in complex industrial conditions. Gyroscopes are not one-size-fits-all sensors, and it's important to select the correct gyro for a given rotation. Two important specifications are range and sensitivity. The range is the fastest rotational speed that the gyro can accurately measure and is measured in degrees per second (°/sec). The sensitivity is the output change in millivolts for a given speed – so the faster the gyro is spinning, the higher the voltage. It is measured in millivolts per degree per second (mV/°/sec).

A rapidly rotating tool would require a high range, like the Analog Devices ADIS16266BCCZ which can measure up to ±14,000°/sec. A slowly rotating arm could be served by an ADI ADIS16060BCCZ which has a range of only ±80°/sec. Analog gyroscopes operating at these low voltages on an industrial robot require low losses for the interconnect. The Mizu-P25 Miniature Waterproof Connectors from Molex is a miniature IP67 sealed connector system which is dustproof and waterproof. It is also suitable for high vibration environments and with a contact resistance of only 10mΩ is suitable for harsh environments low voltage systems.

Sensing Shock and Awe

Robots sometimes bump into things, either accidentally or on purpose. Shock is a sudden change in acceleration, so it can easily be detected with an accelerometer. However, when detecting shock the location of the accelerometer is critical. For example, a robotic hand that accidentally hits the floor is going to see a much more dramatic shock (change in acceleration) at the hand, as opposed to the arm or elbow.

In some cases shock must be detected immediately so a decision and an action can be made immediately. An example of how critical this can be is in a common hard disk drive found in a laptop computer. If the hard drive is dropped and hits a hard floor, an accelerometer in the drive immediately detects the shock. In such an event the hard drive head absolutely must park the head within milliseconds or face the heartbreak of data loss.

Obviously the proper detection of such an event depends upon the proper positioning of the accelerometer on the drive, as well as a reliable processor and solid firmware.

Contrast that to a robotic arm in arm assembly line going through a pre-programmed motion. As noted in a previous section, strategically placed accelerometers will sense the tilt and position of the arm to insure the movement is correct. However, if the movement is interrupted by a blockage it is critical that the resultant shock be detected quickly and reliably. There is a real danger that a person is responsible for the blockage and is now in harm's way. In this situation a dedicated accelerometer is used to detect shock, and in some cases two or more redundant accelerometers, each with their own detection circuits, may be placed to provide absolute safety.

Vibrating Robots

Vibration in a robot is rarely a good thing. It can be an indication of worn bearings, missing components, improper lubrication, incorrect alignment of armatures, or an out of balance load being carried by the robotic system. In this context, vibration is both a maintenance and a safety issue. Monitoring vibration in an industrial robot can be necessary for monitoring machine health, system diagnostics, and safety shutoff sensing.

The Analog Devices ADIS16229 Digital MEMs Vibration Sensor with Embedded RF Transceiver provides a portable vibration sensing platform with wireless support for industrial applications. It provides a complete sensing solution for monitoring and recording vibration in industrial environments. An RF connector like the Molex Brass SMA RF Connectors is mounted on the board, with a threaded coupling to support firm mating under intense vibration. Molex SMA RF Connectors minimize reflection and attenuation at the over 900MHz RF transmission frequencies of this board.

Figure 3*: Analog Devices ADIS16000 Digital MEMs Vibration Sensor and RF Transciever with Molex Brass SMA RF Connector. (Source: Analog Devices)*

Acceleration – Faster and Faster

Detecting acceleration and deceleration is often important for movement sensing. This can mean anything from sensing motion in a robotic arm to determining the robot's position when used in a dead reckoning system. An accelerometer can also be used to determine if an object has been picked up or put down.

A dedicated MEMs accelerometer can be used to determine the acceleration of a robot, totally independent of other sensors. In this situation, if external forces contribute to a robot's behavior and try to accelerate the robot faster than is needed and at a harmful speed, the rapid acceleration can be detected and the robot shut down.

Proximity Sensing

A proximity sensor detects the presence of a nearby object without having to make any physical contact for safety and operational reasons. The [CapSense devices]() from [Cypress Semiconductor]() are able to detect the presence of a nearby object without any physical contact. The [Cypress CY8CKIT-024 CapSense Proximity Shield](), when [interfaced with any Cypress Pioneer kit]() provides a dynamic out of the box proximity sensing development solution. When the CapSense proximity sensor is excited by a voltage source, an electric field is created around the sensor as in Figure 4. Some of the electric field lines are projected into ground and also into nearby space, creating a capacitance that can be measured. If a target object on an assembly line approaches the robot's proximity sensor, some of the electric field lines couple to the target object, changing the capacitance which is then measured by the CapSense circuitry to determine the distance and position of the target object.

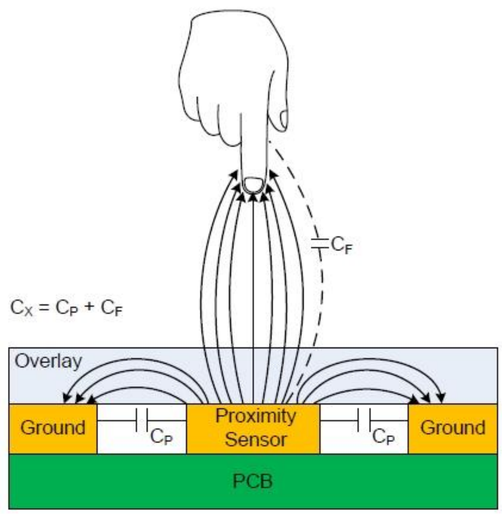

Figure 4*: A Cypress CapSense Proximity Sensor Coupling Electric Field Lines to a Finger. (Source: Cypress)*

For Figure 4:
C_X = Total capacitance measured by the Cypress CapSense proximity-sensing system
C_P = Sensor parasitic capacitance
C_F = Capacitance added by a nearby target object

For robotics applications, this solution provides three dimensional object or gesture recognition. This can be useful for a robot on an assembly line to determine if a target object is within distance. It can also be used to determine if an obstruction is about to interfere with a robot before the impact is measured by a shock sensor.

Conclusion

MEMs sensors are necessary for today's robots for purposes of operational, safety, and maintenance. Gyroscopes and the ever versatile accelerometer form the heart of a robot's sensor network, with more esoteric sensor systems used for proximity sensing. Advanced MEMs sensors, with solid interconnect solutions are expanding the capabilities of today's robots, providing operational and safety abilities that enhance performance while reducing costs.