Position, Velocity, and Acceleration

So far in this class we have covered a number of different sensing technologies and then briefly discussed some of the variables we can sense with them. Now we will consider some sensing needs and look at technologies that can be used for them. Specifically we will consider a variety of methods to measure position, velocity, and acceleration.

Position

Position measurement is so widely used that we need to refine the definition further. We can measure absolute position, we can detect proximity or we can measure differential position (displacement).

Absolute Position - Location of the object's coordinates with respect to a selected reference in one, two or three dimensions.
Proximity - A critical distance signaled by an on/off output.
Displacement - Movement from one position to another for a specific distance or angle.

These position measurements could be in a single direction or up to three dimensions in Cartesian (x, y, z) coordinates or rotary coordinates (?, f, ?) or some combination of these. The commonest three dimensional rotational systems are known as cylindrical (R, ?, z) and spherical (R, ?, f).

Specific applications often have several sensor options and it is difficult to determine the best transducer for the job. Position transducers are available in thousands of configurations. There are probably more options for measuring position than for any other type of sensed variable. To design or select a position sensor it is necessary to be aware of the parameters that affect the choice and also their relative importance. Once these are defined then the selection of the technology and the specific sensor becomes much easier.

Here is a list of parameters that should be considered.

Parameter	**Options**	**Comment**
Motion	Rotary or linear	Rotary can often be converted to linear and vice-versa
Dimensions	1 to 3	2 or 3 dimensions can be constructed from one dimensional systems
Type	Absolute or differential	Differential position is often incremental
Measured/ detected	Continuous or discrete measurement	Position detectors are often called proximity sensors.
Contact	Contact or non-contact	Contact is generally cheaper but could easily be the better technical solution too.
Response time	DC or bandwidth required	
Range	Microns to Km	Most sensors work within a couple of inches to feet. Longer range ones trend to be specialized.
Accuracy	Repeatability,	May be able to compensate for some of these

	resolution, linearity, hysteresis	with conditioning or processing in computer. (see calibration)
Signal	Digital or analog, voltage, current, resistance, frequency, other	Must match signal to measuring system. Both voltage(current) and impedance may be important. Smart sensors may output a fieldbus compatible signal. Telemetry may be required.
Single or system	Sensor or transmitter/sensor system.	Transducers may require a special transmitter to send out a signal
Conditioning	Special transducer or standard electrical signal	Power supply (active vs. passive sensor), need for conditioning in the field vs. remotely.
Calibration requirements	Never, Regular or self-calibrating	Lifetime cost and access implications. Do replacement sensors need new calibration or all sensors identical?
Installation conditions	Environment (heat, vibration, humidity etc.)	May be able to block humidity etc. Can often compensate for temperature.
	Size/weight	
	Portable/fixed	Portable units have power implications (battery life - power/charge and charge-cycles)
	Electrical Noise	
	Dust / visibility	Especially for optical sensing
Price	Pennies to millions	Purchase, labor and lifetime costs included
Expected life	Once to millions	Biomedical sensors are often designed for high reliability but single usage.

A sample of position measurement technologies

- Potentiometer (slide or rotary)
- LVDT (linear)
- RVDT (rotary)
- Inductive
- Ultrasonic
- Capacitive
- Hall Effect devices
- Eddy currents
- Laser
- RF
- Encoders
- Strain Gage (using Hooke's law or measuring very small movements (strains) in a solid)

- Resolver or synchro (discussed under closed loop systems, see below)

Specialized position measurement can take advantage of environmental factors. For example altitude is commonly measured by measuring atmospheric pressure. Two-part measuring systems are also frequently used. These involve a transmitter and a receiver. Some examples include GPS, encoders, and pulsed ultrasonic or emf wave systems. Closed loop systems are another form of instrumentation systems as opposed to single sensors.

Velocity

To measure linear velocity, it is generally easiest to measure acceleration or position and take the integral/derivative respectively thereof. Note that there are problems when integrating numerically. An integration process will continually integrate any offset error in the systems until it saturates the system. Integration must be designed with "anti-windup reset" capabilities of similar. This periodically resets the system so that if the calculation is saturated (integrated to "infinity") then it starts over again. Numerical differentiation is easier.

Some technologies do measure velocity directly such as those based on the Doppler effect. Velocity measured using the Doppler effect was discussed with sonic methods.

Doppler effect sensors are also used with RF and other electromagnetic waves. The basic Doppler equation is $V_{TARGET} = V_{MEDIUM} (1 - f_{TX}/f_{RX})cos(?)$. The velocity of the medium is the speed of sound for sonic devices and for microwave, RF or light based devices it is the speed of light.

Here is another example of a direct measurement of velocity. This one is designed for short distances only. The sensor is called a *linear velocity sensor* and works best at measuring vibration movements (see figure below). This sensor is based on Faraday's law. Where a conductor having length, L, moving with a velocity, v, in a direction perpendicular to a magnetic field of flux density, B, induces a voltage, V, in the conductor. When the magnetic flux is held constant, the induced voltage output is directly proportional to velocity.

$$V=LvB \quad \text{or} \quad v = V / LB = K.V$$