# ENGIN 112: Module 8–Signals and Timing

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## 1 Positioning

Historically, positioning has been a very important problem, particular in navigation. There are two components to describing a location: longitude and latitude. Latitude can be determine at night by measuring the angle between Polaris (the north star) and the horizon and during the day by measuring the angle between the highest point of the sun's path and the horizon. A much more difficult problem is to determine latitude accurately.

For any measurement, it is important to understand its accuracy (i.e., how close the average of the measured values is to the true value) and its precision (i.e., how close repeated measurements are to each other). When errors are encountered, then it is important to distinguish between random errors and systematic errors. Random errors are expected to zero out over multiple, repeated measurements, systematic errors do not.

### 1.1 Dead Reckoning

Navigation by dead reckoning starts from a known location. The current position is determined by adding up all the incremental movements that have been made since the beginning. This process can work in principle. However, errors accumulate in each step and long journeys can lead to inaccurate positioning.

### 1.2 Keeping Time

The most successful solution to determining longitude accurately that was used for navigation in practice is to keep an accurate clock. By determining the time difference between noon at the home port and the time that the sun reaches the zenith at the local position determines the angular distance between the home port and the local position (based on the sun moving 360 degrees in 24 hours).

There are a number of different mechanical designs that can achieve highly accurate timekeeping. The most accurate clocks measure physical properties (such as atomic vibration) and relate these measurements to the progression of time. Time information from such atomic clocks is distributed through the Internet (e.g., Network Time Protocol) or special radio stations on different continent.

  

# 2 Global Positioning System

The Global Positioning System (GPS) makes use of trilateration. In this process, location is determined by measuring distances between known reference points and the GPS receiver's position. GPS satellites that move on well-known orbits represent the known reference points. Each of them sends a signal with current, synchronized timing information. Distances between the satellites and the receiver are measured by determining the propagation time of the electromagnetic radio signal. Satellites that are closer to the receiver will appear to be "ahead" in time; satellites that are farther will appear to be "behind" (since the more recent time signal has not yet propagated to the receiver).

GPS receivers are widely used in embedded systems. A receiver typically outputs the location information as a "GPS sentence," which contains position information, time information, and various status reports (e.g., number of visible satellites, accuracy, etc.).

# 3 Beamforming

Another example, where signal propagation time is used is beamforming, where multiple sensors (typically linearly aligned) are used to determine the angle of an incoming signal (or selectively isolate a signal that is arriving at a particular angle to the array). The propagation delay of a signal causes slight delays in arrival time of that signal along the sensors of the array. Based on the angle, propagation speed of the signal, and distance between sensors, this delay can be determined (see slides for equation).

In the example of acoustic beamforming, signals from each microphone can be shifted by the expected delay. When adding the signals together after shifting, the signal from the that particular angle interferes constructively, resulting in a higher amplitude (whereas signals from other angles do not add up constructively). Thus, sound from a particular angle can be sensed more strongly.