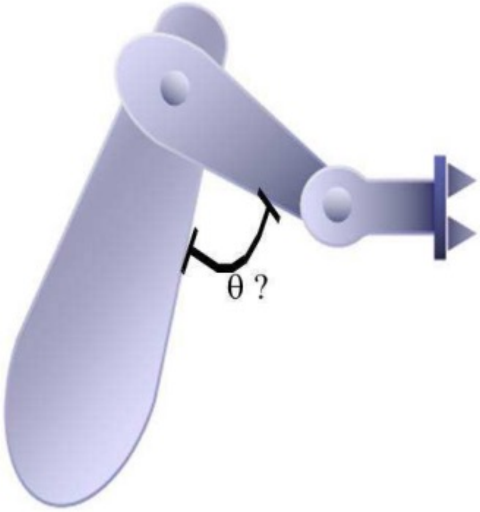
EEE 187 Robotics



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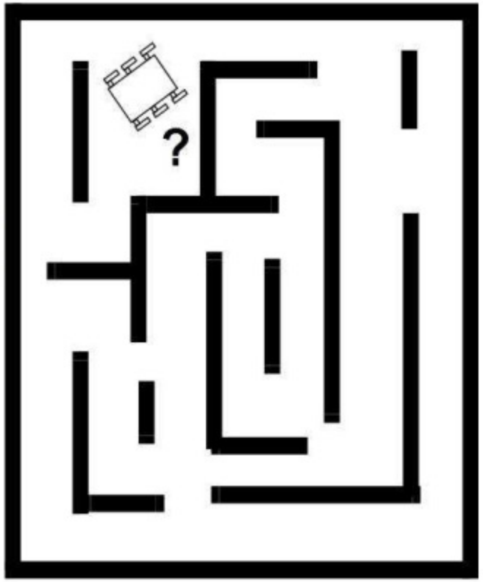

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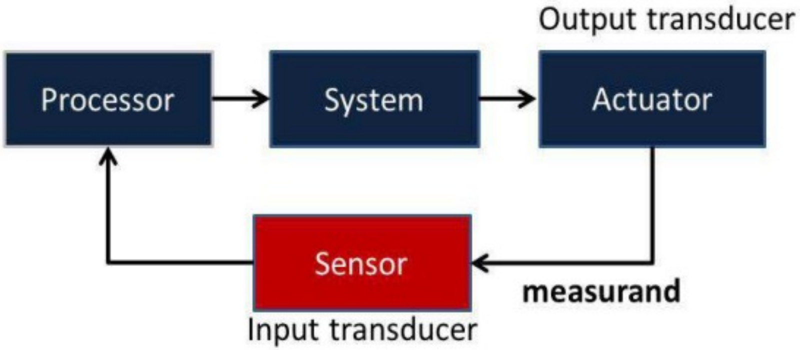

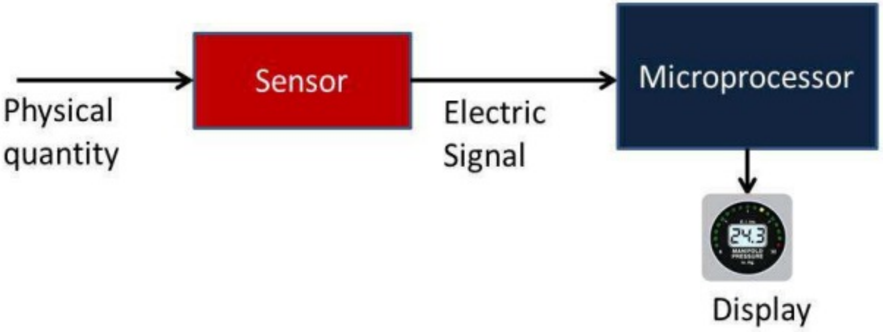

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- Sensors are used to
  - Acquire knowledge about the environment
    - External interaction with the world

  - Acquire knowledge about the internal state of the robot
    - Feedback Control

  - Classification of sensors
    - Proprioceptive vs Exteroceptive
      - Internal vs Environmental
    - Analog vs Digital
    - Active vs Passive

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- Sensor Characteristics
  - Dynamic Range
  - Repeatability
  - Resolution
  - Linearity
  - Frequency of measurements
  - Sensitivity
  - Error
  - Accuracy

Systematic Error
Random Errors
Reproducibility
Precision
Dynamic Characteristics
Hysteresis

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- Sensors for Mobile Robots
  - Accelerometer
  - Gyroscope
  - Compass
  - Inclinometer (angles of slope)
  - Visual Sensors
  - Satellite Based Sensors (eg GPS)
  - Contact Sensors (eg Bumpers and Wiskers)

  Triangulation and Trilateration

  Sonar Sensing

  QTI Line Sensor (IR)

Proximity Sensors and Range Finders

- Sonar (time of flight)
- Radar (phase and frequency)
- Laser range-finders
- Infrared

Position Sensors

- Encoders
- Potentiometers

Sniff Sensors

Sonar Beam Pattern

Global Positioning System

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$$\gamma = \arctan \frac{u}{f}$$

Using trigonometry, we can find:

$$L = B \tan(\alpha + \gamma)$$

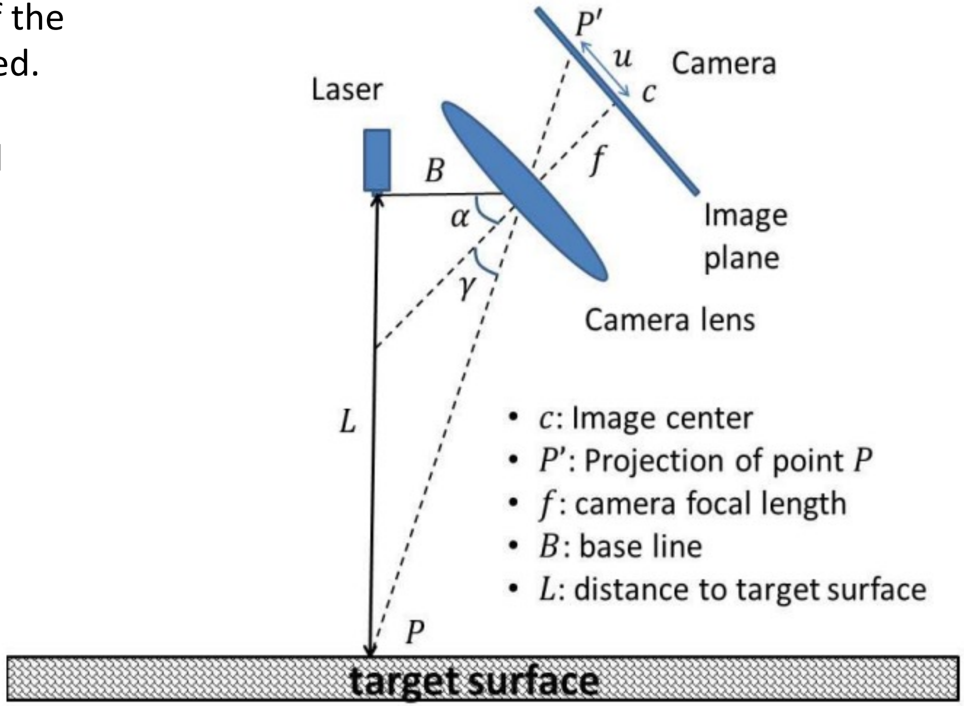
Optical triangulation

This is another method used to determine range.

Triangulation can be defined as follows: If the length of one side and two interior angles are known, then the length of the two remaining sides and the other angle can be determined.

An optical triangulation device that has two components

- Culminated Light Source: Any focused light can be used including laser
- Camera: Position sensitive device



In this example B (the baseline), ∝ (the angle between the camera optical axis and the laser beam) and f (the focal length of the camera) are known and given. However L (distance from the laser to the target surface) and γ *are not known*. However when the laser projects a pattern of light onto the target surface, p' is the position of point P in the pixel reference frame, and we can determine γ as follows;

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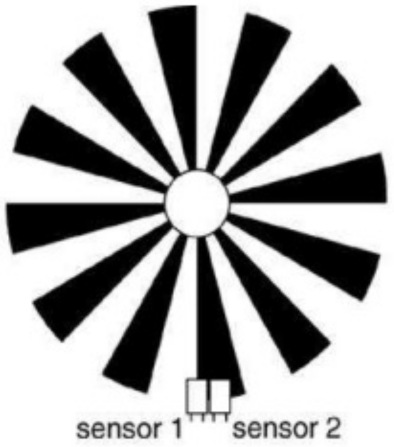
Position Sensors and Encoders

Position sensors are used to measure displacement, rotary and linear. In many situations, the position information is used for velocity calculation.

Encoders are electromechanical devices that convert the angular position or motion of a shaft or axle into an analog or digital quantity.

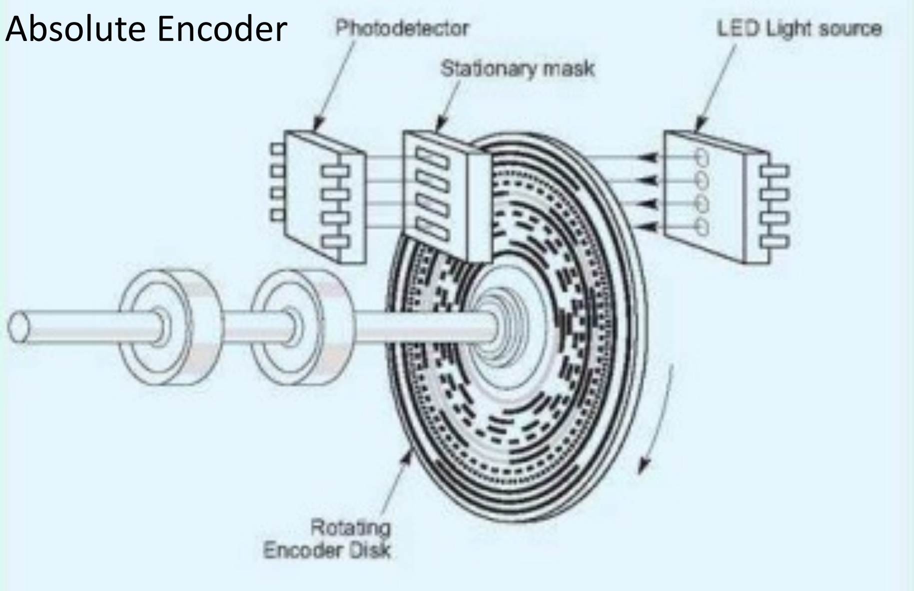
- A rotary encoder measures the rotation of a shaft or axle. Rotary encoders are used for example to measure the angle of a robotic arm, or how far a mobile robot have moved by measuring the rotations of its wheels.

- A linear encoder is similar to a rotary encoder, but measures position in a straight line, rather than rotation. There are two types of encoders: absolute and incremental.



Incremental Encoders

Absolute Encoder



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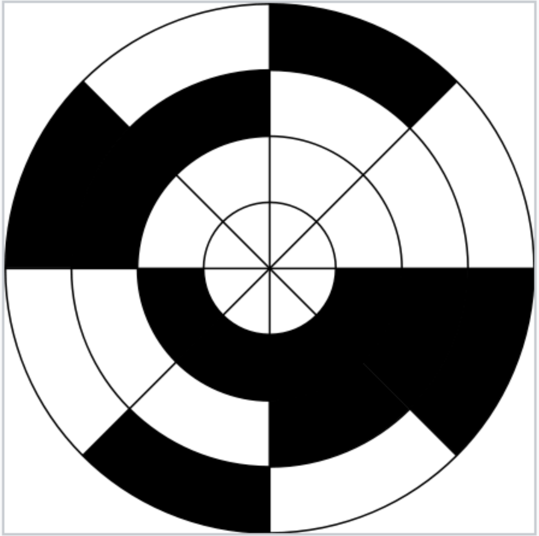
Standard Binary Encoding

An example of a binary code, in an extremely simplified encoder with only three contacts, is shown.

Standard Binary Encoding

Sector	Contact 1	Contact 2	Contact 3	Angle
0	off	off	off	0° to 45°
1	off	off	ON	45° to 90°
2	off	ON	off	90° to 135°
3	off	ON	ON	135° to 180°
4	ON	off	off	180° to 225°
5	ON	off	ON	225° to 270°
6	ON	ON	off	270° to 315°
7	ON	ON	ON	315° to 360°

In general, where there are n contacts, the number of distinct positions of the shaft is 2^n. In this example, n is 3, so there are 2^3 or 8 positions.



Rotary encoder for angle-measuring devices marked in 3-bit binary. The inner ring corresponds to Contact 1 in the table. Black sectors are "on". Zero degrees is on the right-hand side, with angle increasing counterclockwise.

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Working principle of encoders

A typical encoder uses optical sensor(s), a moving mechanical component, and a special reflector to provide a series of electrical pulses to the microcontroller.

Incremental Encoders : An incremental rotary encoder provides cyclical outputs when the shaft is rotated. The arcs of clear and opaque sections are all equal and repeating. Each arc indicates an angle of revolution. The accuracy increases with the number of divisions. For example, if the wheel is divided into two potions, the resolution is 180^o , if the wheel is divided into 16 positions, the resolution is 22.5^o . Typical incremental encoders can have 512 to 1024 arcs in them. This type of encoder does not directly indicate the value of the actual position.

Absolute Encoders : There are multiple rows of arcs: The first one has only one clear and one opaque arc (one on, one off), the next row would have 4 sections, and the next one would have 8. Each row must have its own light source and light sensor. Each sensor sends out a signal, the position is obtained by combining information from all rows

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Sonar Sensing

SONAR SENSING Sonar or ultrasonic sensing uses propagation of acoustic energy where acoustic pulses and their echoes are used to measure the range to an object. Ultrasonic uses frequency higher than audible frequency (frequencies between 20Hz and 20KHz). PING for example uses pulses at 40KHz.

Ultrasonic sensors are popular in robotics. Their popularity is due to the following:

- Low cost
- Light weight
- Low power consumption
- Low computational effort

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Sonar Sensing

Ultrasonic sensors are used for different purposes including

- Obstacle avoidance
- Sonar mapping: perform rotational scan (360 for example) to construct of a map of the environment.
- Object recognition: a sequence of sonar maps is processed using data fusion algorithms.

Ultrasonic sensors use the time of flight to determine the range:

$r_o = v_s t_o /2$

where

- v_s is the speed of sound, approximately 343 m/s at standard temperature and pressure.
- r_o is the object range
- Division by 2: round trip

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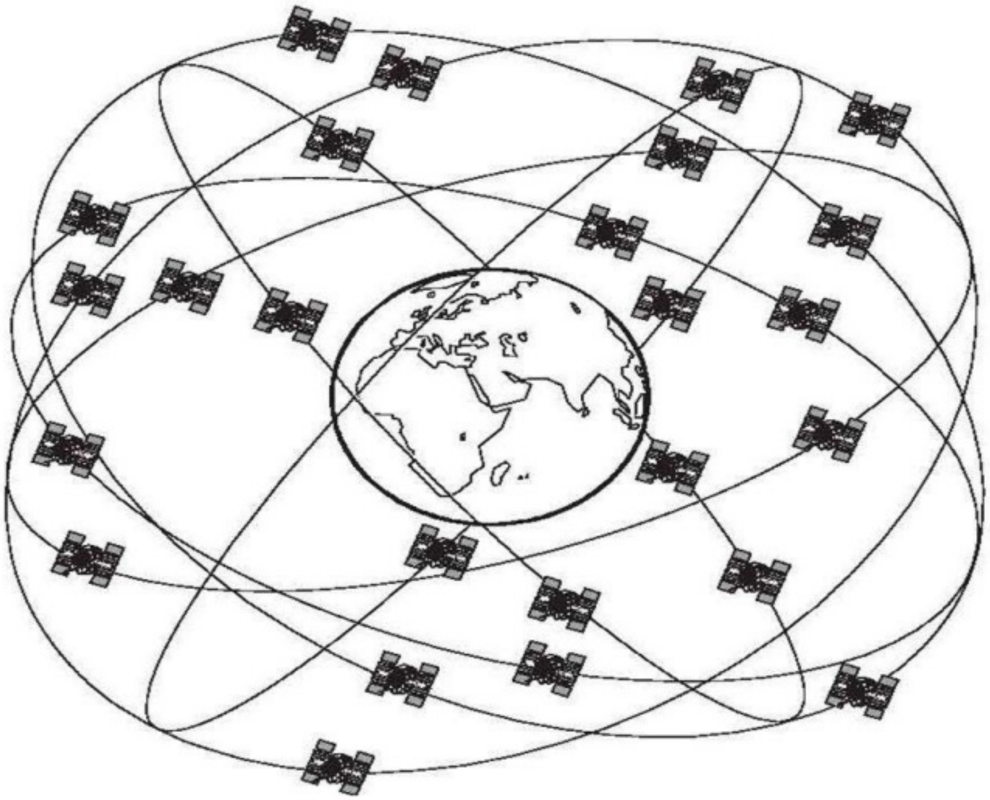
GLOBAL POSITIONING SYSTEM (GPS)

GPS is the most commonly used mechanism for location estimation and navigation. It provides a 3 dimensional position estimate in absolute coordinates (longitude, latitude and height co-ordinates) accurate to within a range of 20m to 1mm, as well as time and date (Universal Time Coordinates (UTC)), accurate to within a range of 60ns to 5ns. The GPS is based on 24 satellites + additional satellites. The satellites are organized into six orbital planes with four satellites in each. GPS is available anywhere on earth.

4 unknowns:

3 ⟶ precision (x,y,z)

1 ⟶ time



The GPS system

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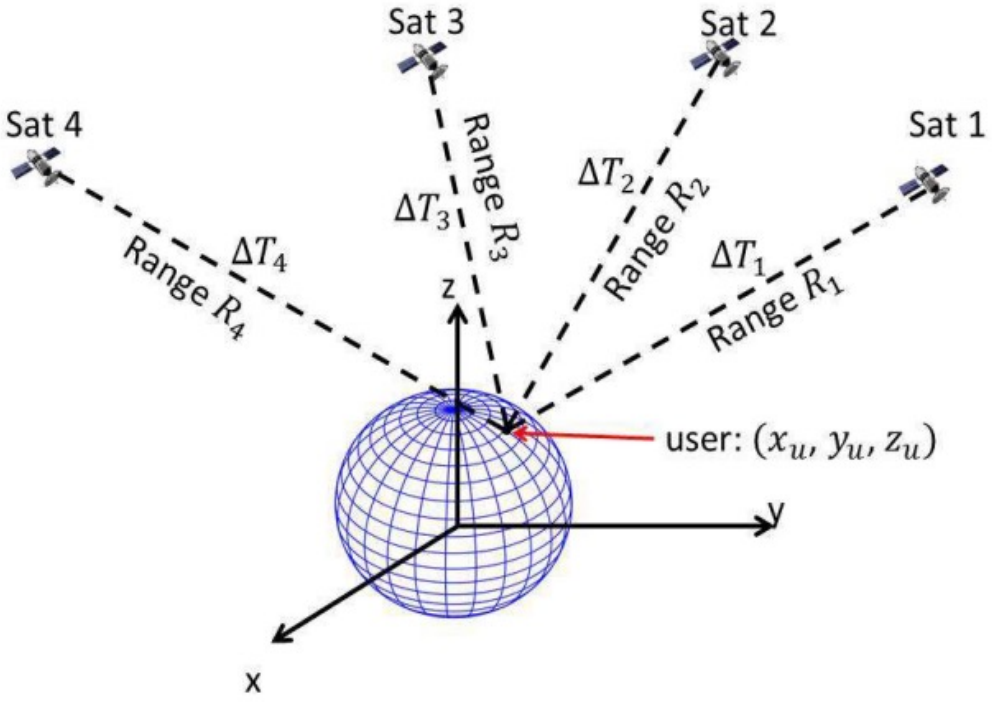
Simplified Pseudo-range Model

Receivers record data at regular, specified intervals (say, every 30 seconds, as instructed by the receiver user). It is the reading of the receiver clock time T, which is used to say exactly when the measurement is sampled. Therefore, the value of T at a measurement epoch is known exactly and is written to the data file along with the observation. (What is not known, is the true time of measurement). The actual observation to satellite s can be written:

$$P^s = (T - T^s)c$$

where T is the known reading of the receiver clock when signal is received, T^S is the reading of the satellite clock when the signal was transmitted, and c is the speed of light (in a vacuum) = 299792458 m/s



The trilateration process

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Simplified Pseudo-range Model

The coordinates of the GPS satellites are known in a global reference frame. To determine the global position, the GPS receiver uses signals from four different satellites. We have four signal transit times ΔT_i (i = 1, ..., 4). The range of the user from the satellite is denoted by R_i , i = 1, ..., 4.

This is the true range or the geometric range. The location of the satellites is known. The satellites clocks are synchronized, the time at which the satellites send the signal is known very precisely. However, the received clock is not synchronized, the receiver clock is slow or fast by ΔT_0. A positive value of ΔT_0 means the received clock is fast and a negative value means the receiver clock is slow. We do not know ΔT_0.

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Simplified Pseudo-range Model

The pseudo range can be calculated using the following equation:

$$PSR_i = c\Delta T_{measured,i} = c(\Delta T_i+\Delta T_0) = R_i+c\Delta T_0$$

where

- R_i is the range between satellite i and the receiver (user)
- c is the speed of light
- ΔT_i is the signal transit time from the satellite to the user.
- ΔT_0 is the difference between satellite clock and user clock. In other words the offset of the user clock.
- PSR_i is the pseudo range

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Simplified Pseudo-range Model

We can write for each satellite:

$R_i = \text{SQRT}\left[(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2\right]$

and

$PSRi = R_i + c\Delta T_0$

Because we have four unknown variables: (x_u, y_u, z_u) and Δt_0, we need four independent variables to solve

$PSRi = \text{SQRT}\left[(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2\right] + c\Delta T_0$

$i = 1, ..., 4$

from which we can solve for the position of the user

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Simplified Pseudo-range Model

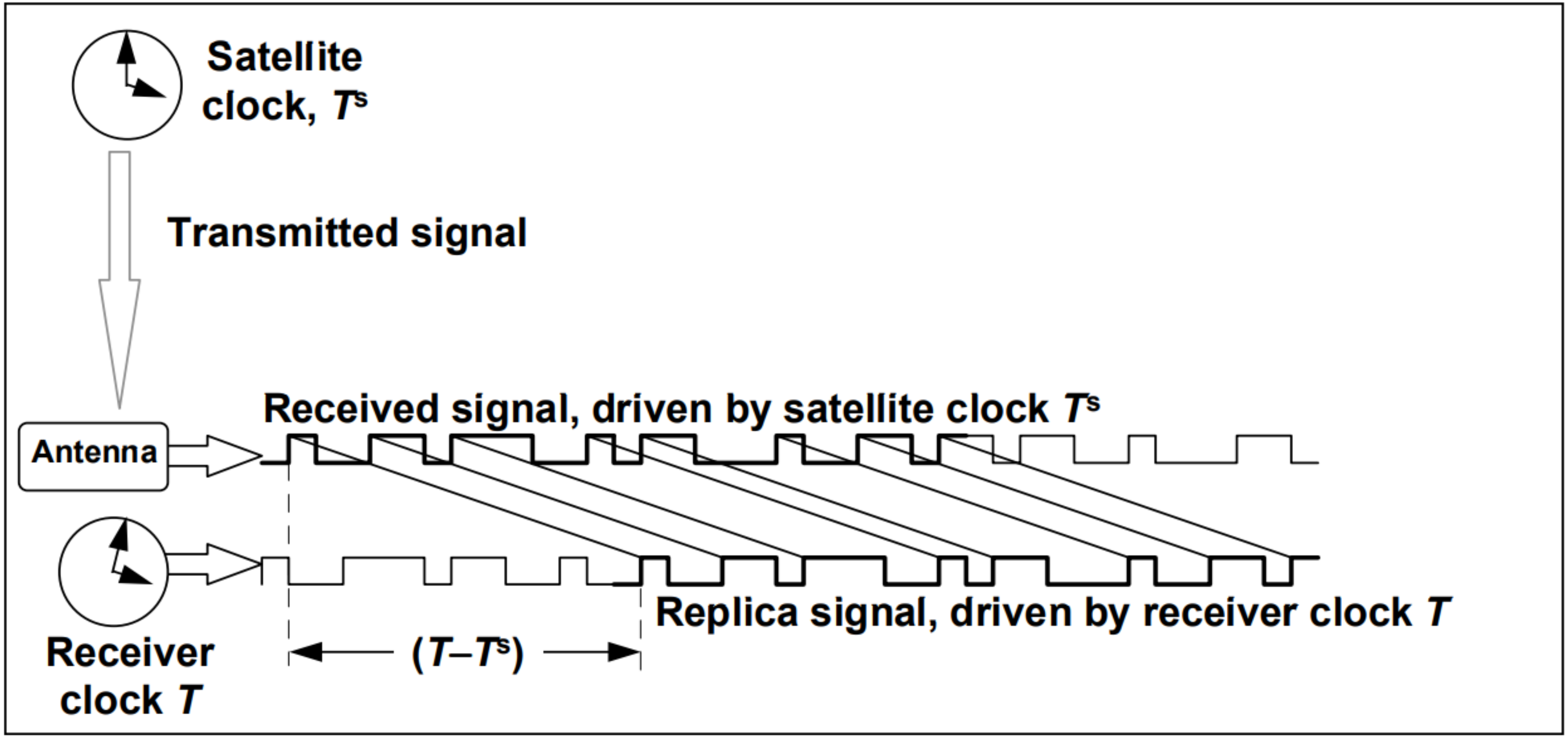

Figure 1: A schematic diagram showing how the GPS pseudorange observation is related to the satellite and receiver clocks.

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LASER RANGE FINDERS

Laser stands for: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Light is a form of electromagnetic radiation but Laser has some different and interesting properties. Because of their properties, lasers are used in a wide variety of applications. Laser corresponds to intense beams of light which is monochromatic, coherent, and highly collimated. The wavelength of laser light is extremely pure (monochromatic, single color) when compared to other sources of light. Light from a laser typically has very low divergence. It can travel over great distances or can be focused to a very small spot with a brightness which exceeds that of the sun.

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LASER RANGE FINDERS

Different techniques can be used to measure ranges using laser such as

• Time of flight (ToF): very similar to ultrasonic sensors. For lasers, electronics capable of resolving picoseconds are required, thus the circuitry is expensive. The ToF method is typically used for large distances such as hundreds of meters or many kilometers.

• Phase shift measurement: uses an intensity-modulated laser beam with a constant frequency and measures the phase difference between transmitted and received signals as shown in figure 15. The wavelength of the modulating signal is λ with

$$\lambda = c /f$$

The distance to the object is given by

$$D = \lambda\theta /4\pi$$

where θ is the measured phase difference between the transmitted and the reflected light beams.

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LASER RANGE FINDERS

Example

Assume that the modulating signal has a wavelength of $\lambda = 60m$ ($f = 5MHz$), what is the phase measurement for a range of:

- a range of $5m$?
- a range of $35m$?

Solution

In both cases we have

$$\theta = 60^o \tag{22}$$

There is an ambiguity interval for λ. It is possible to decrease the ambiguity interval by increasing λ. For example, if $\lambda = 120m$, $D = 5m$ will be confused with $D = 65m$.