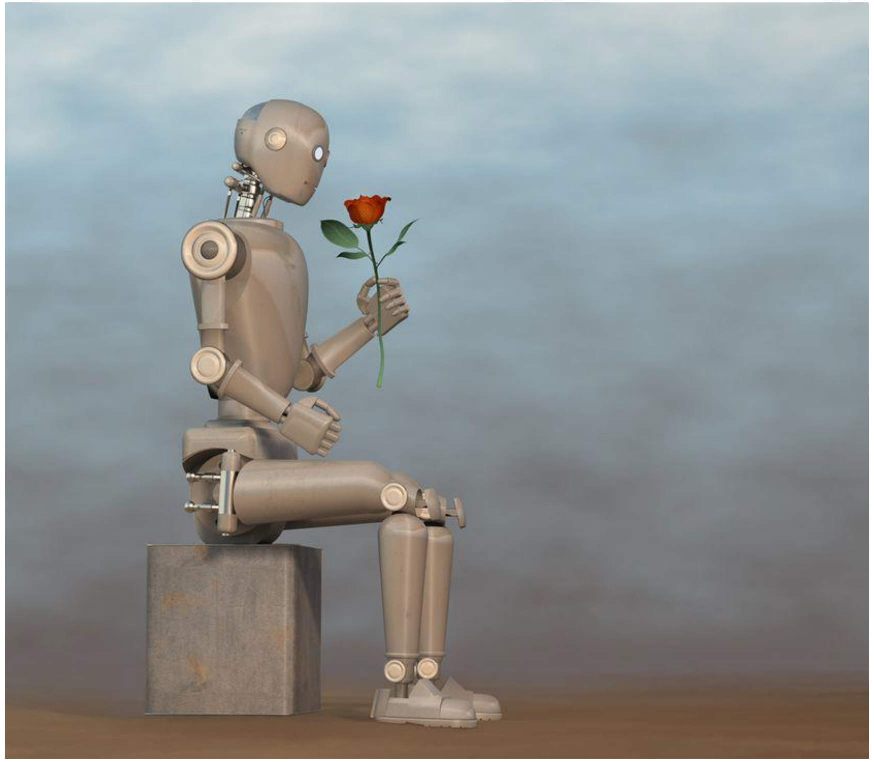
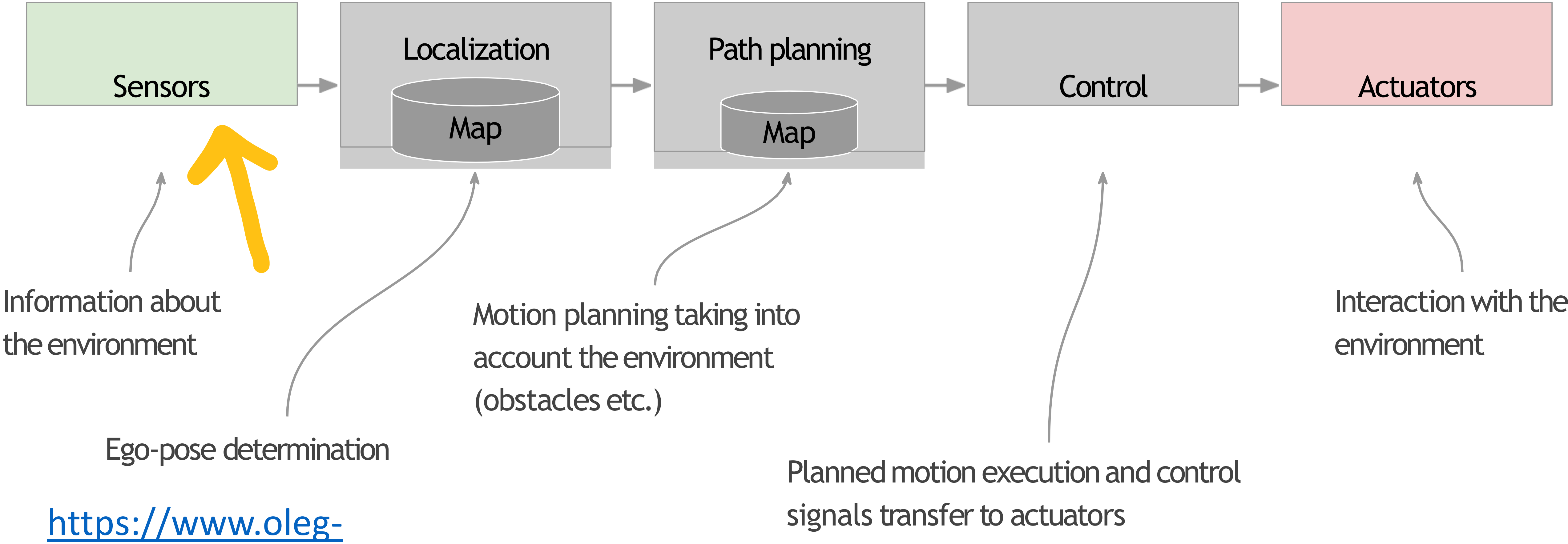
SENSORS



ROBOT = SENSORS + ACTUATORS + COMPUTERS

(SIMPLIFIED) CONTROL SCHEME OF MODERN MOBILE ROBOT



Information about the environment

Ego-pose determination

Motion planning taking into account the environment (obstacles etc.)

Planned motion execution and control signals transfer to actuators

Interaction with the environment

https://www.oleg-shipitko.com/_files/ugd/802739_54bf93fd34534080be9512b09bc545b5.pdf

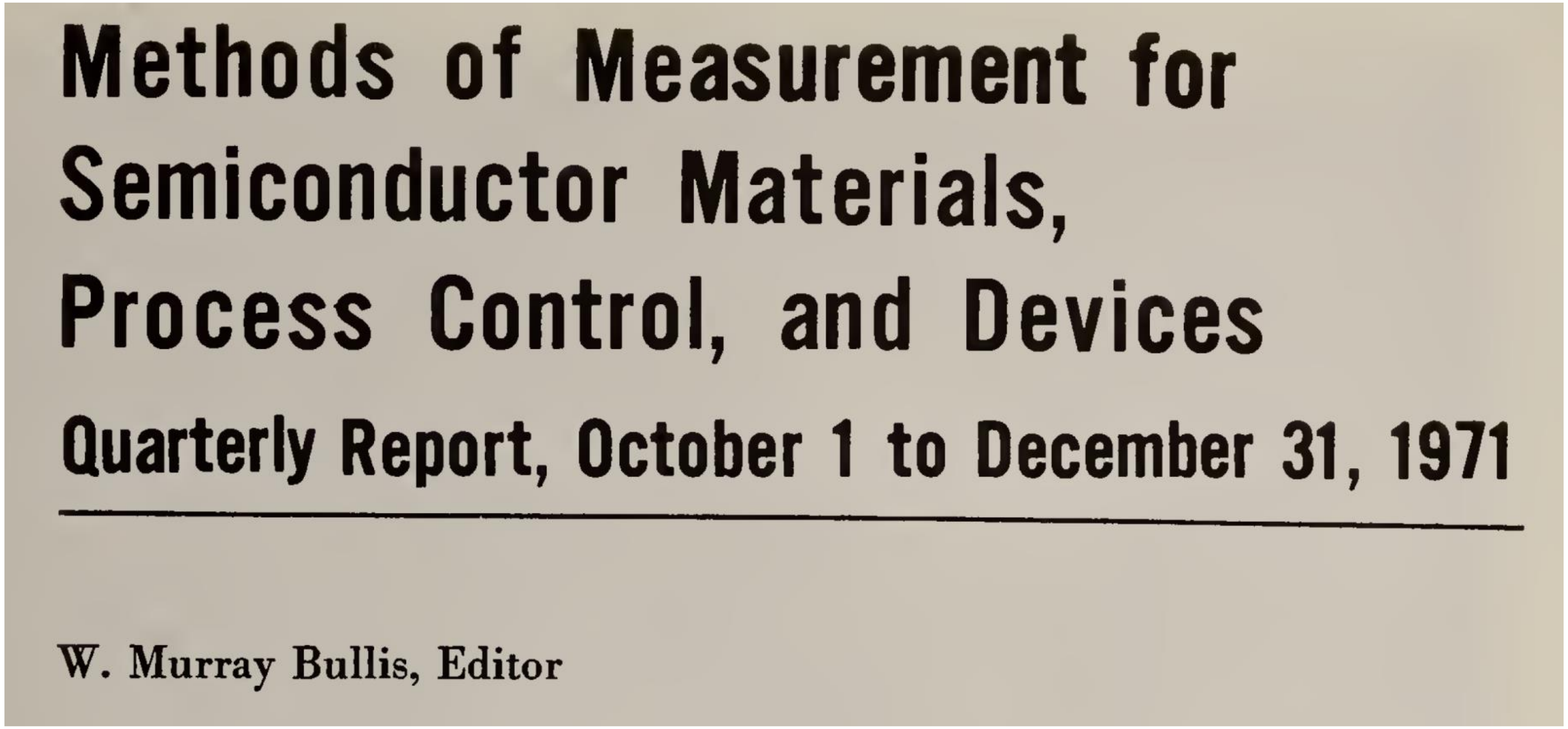
A **sensor** is a device that produces an output signal for the purpose of sensing of a physical phenomenon.
In the broadest definition, a sensor is a device, module, machine, or subsystem that detects events or changes in its environment and sends the information to other electronics, frequently a computer processor. Sensors are always used with other electronics.

Devices which perform an “Input” function are commonly called **Sensors** because they “sense” a physical change in some characteristic that changes in response to some excitation, for example heat or force and covert that into an electrical signal. Devices which perform an “Output” function are generally called **Actuators** and are used to control some external device, for example movement or sound.

https://www.electronics-tutorials.ws/io/io_1.html

Electrical **Transducers** are used to convert energy of one kind into energy of another kind, so for example, a microphone (input device) converts sound waves into electrical signals for the amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves.

The **National Bureau of Standards** (NBS) was founded by Congress on March 3, 1901 as an authoritative domestic **measurement and standards** laboratory, and was the first physical science research laboratory of the federal government. In 1988, the National Bureau of Standards was renamed the National Institute of Standards and Technology (NIST).



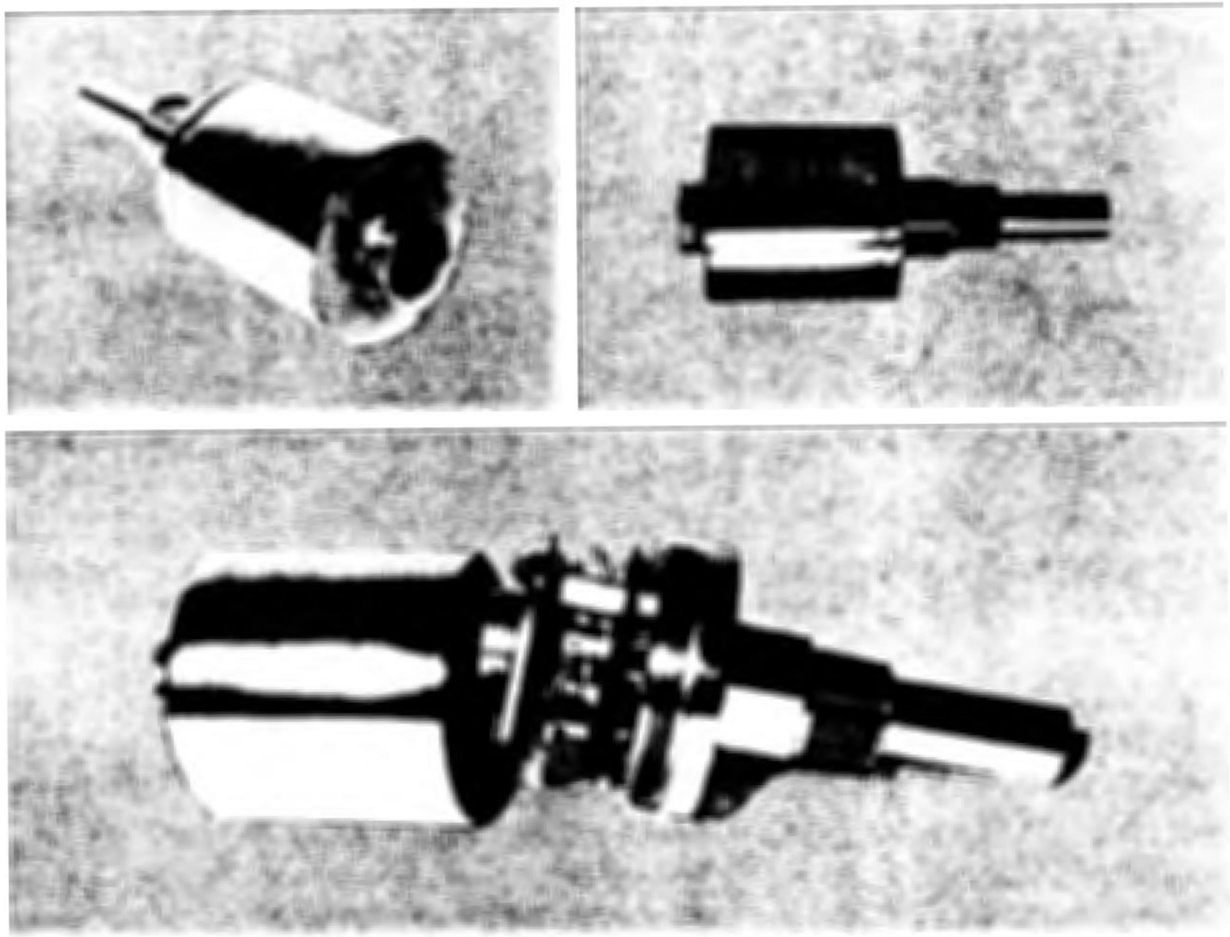
Methods of Measurement for Semiconductor Materials, Process Control, and Devices

Quarterly Report, October 1 to December 31, 1971

W. Murray Bullis, Editor

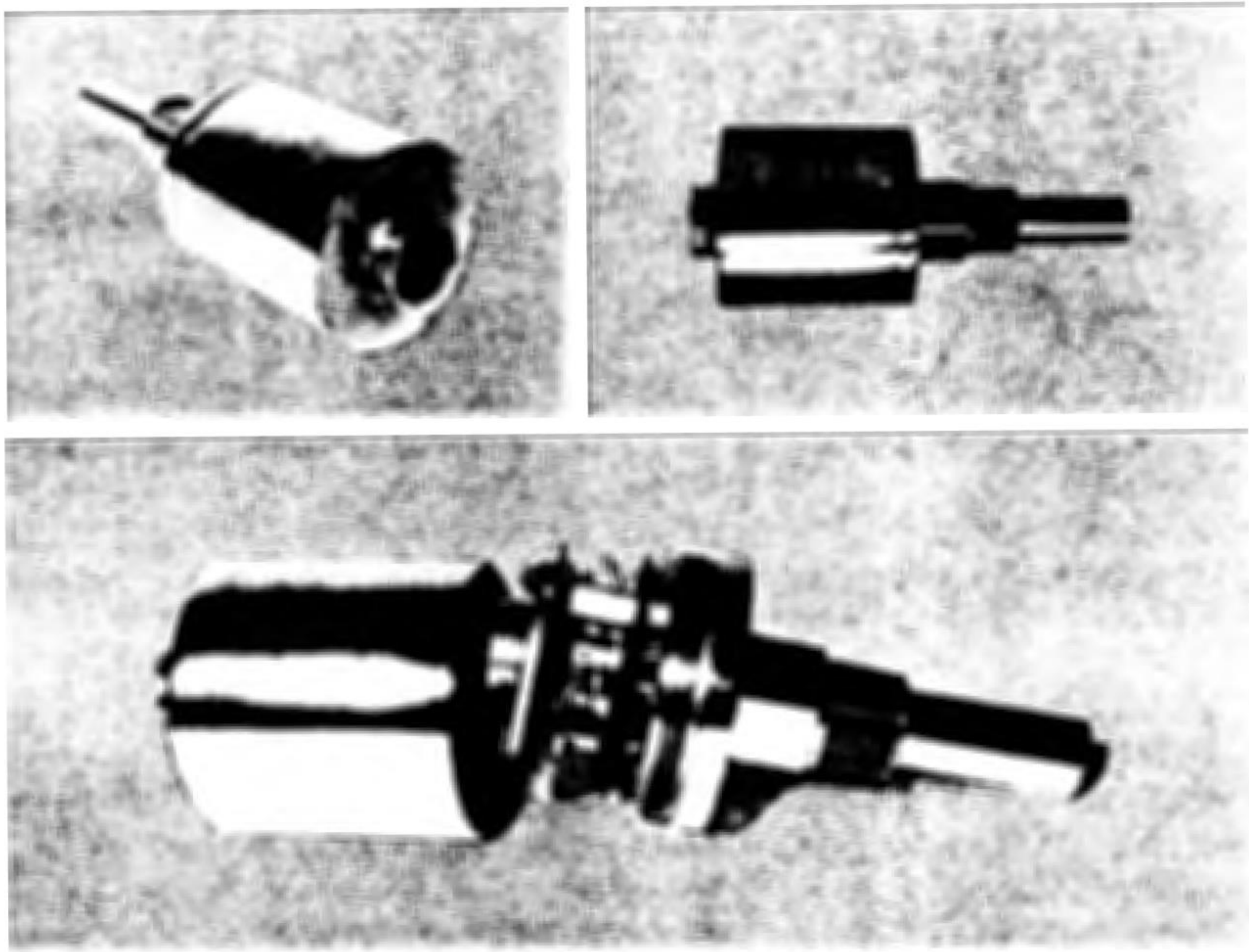
Lockheed Electronics Company, Inc.

DACS Data Acquisition & Control Systems



Introduction

The temperature-current device (**TCD**) temperature sensor provides a breakthrough in low cost accurate temperature measurement. By taking advantage of the temperature sensitivity of a transistor's base-emitter voltage, a semi-conductor temperature transducer has been developed that provides a large and highly linear output. It eliminates the need for signal conditioning amplifiers, cold-junction compensators, and other costly accessories required by conventional temperature sensors (thermocouples, thermistors, and resistance-temperature devices). The output of the **TCD** temperature sensor is an industry standard 4 to 20 mA analog signal that may be sent directly to a central supervisory control and data acquisition (SCADA) computer or applied to a remote terminal unit (RTU) at the measurement location.



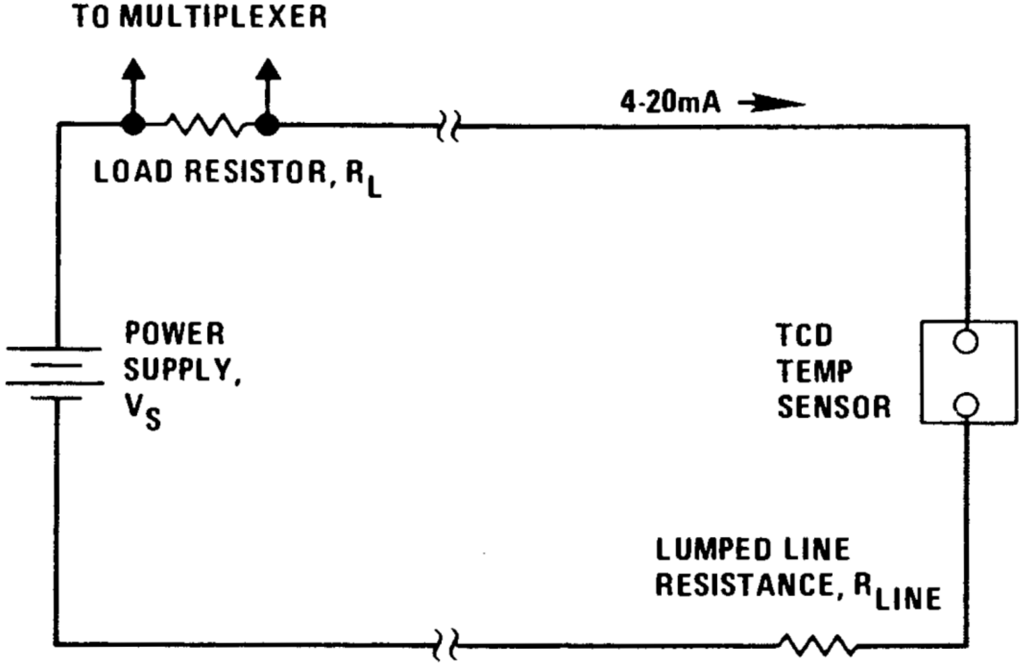


Figure 1

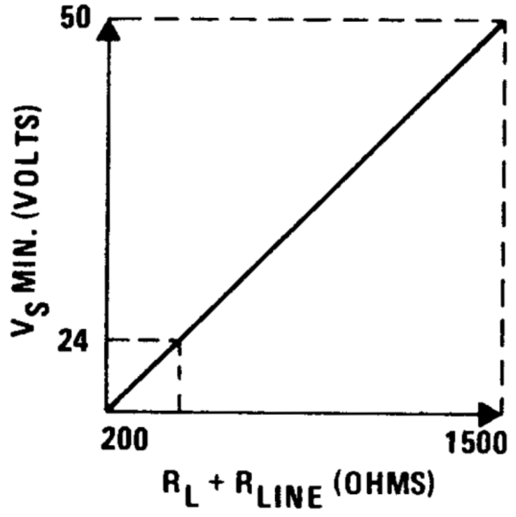


Figure 2

Special Features

- Solid-state sensor and amplifier elements
- Two-wire output
- Practically unlimited lead length
- High accuracy and linearity
- Choice of three ranges:

-55 to + 45° C (-67 to + 113° F)
0 to + 100° C (32 to + 212° F)
-15 to + 125° C (5 to + 257° F)

Specifications and Performance Characteristics

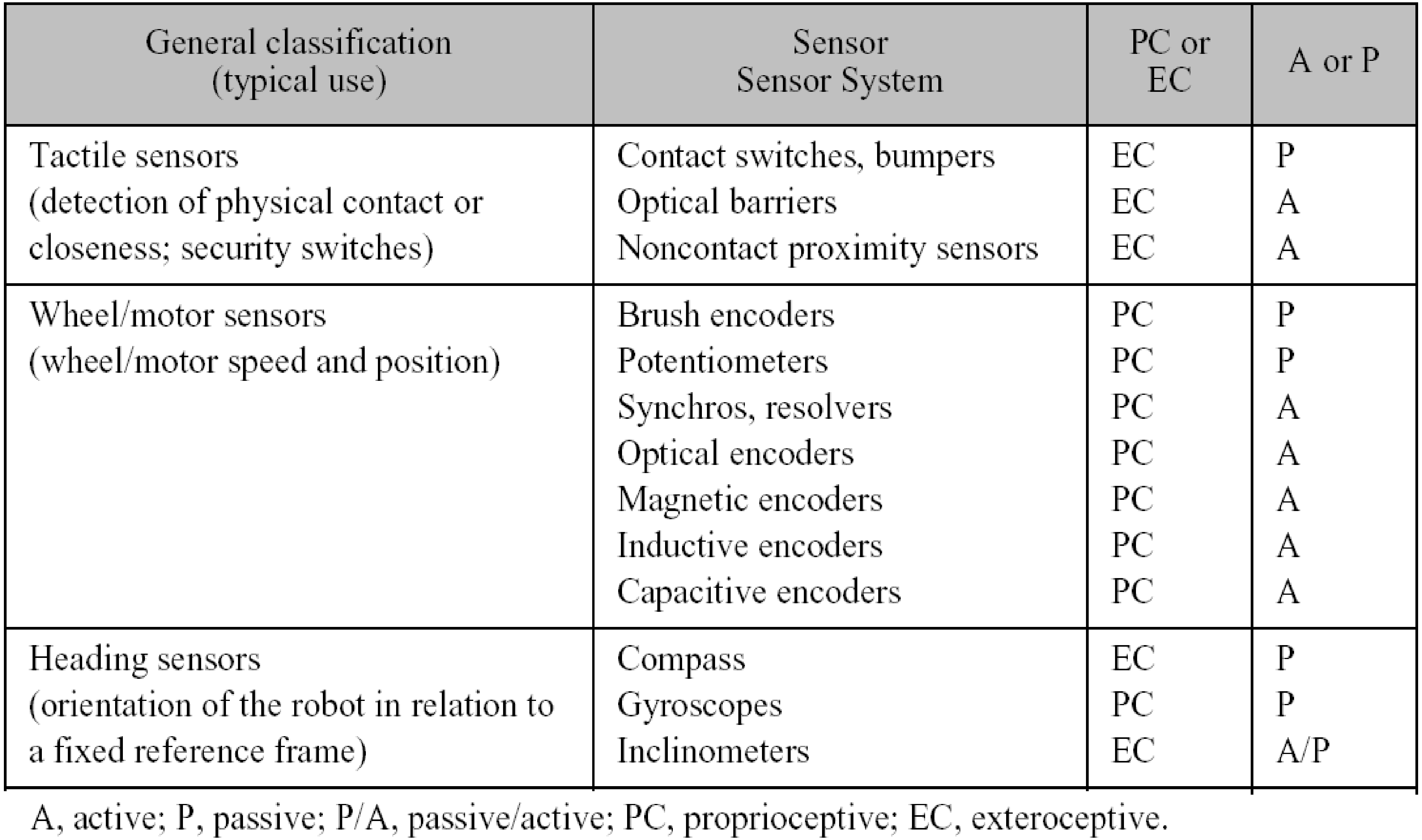
• Maximum Supply Voltage	50 Vdc
• Minimum Supply Voltage	See Figure 2
• Operating Current Range	3 to 22 mA
• Maximum Line and Load Resistance (See Figure 1)	1500 ohms
• Thermal Time Constant	Less than 10 sec
• Accuracy	0.5% of span
• Repeatability	0.2%
• Linearity	0.5% of span
• Output	4 - 20 mA in calibration range

Classification of sensors

- **Proprioceptive** (“sense of self”, internal state).
  - Measures values internally to the system (robot), e.g. battery level, wheel position, joint angle, etc.
- **Exteroceptive** (external state).
  - Observations of robot environment, objects in it.

- **Active** (emits energy, e.g. radar) vs.
- **Passive** (passively receives energy, e.g., camera).

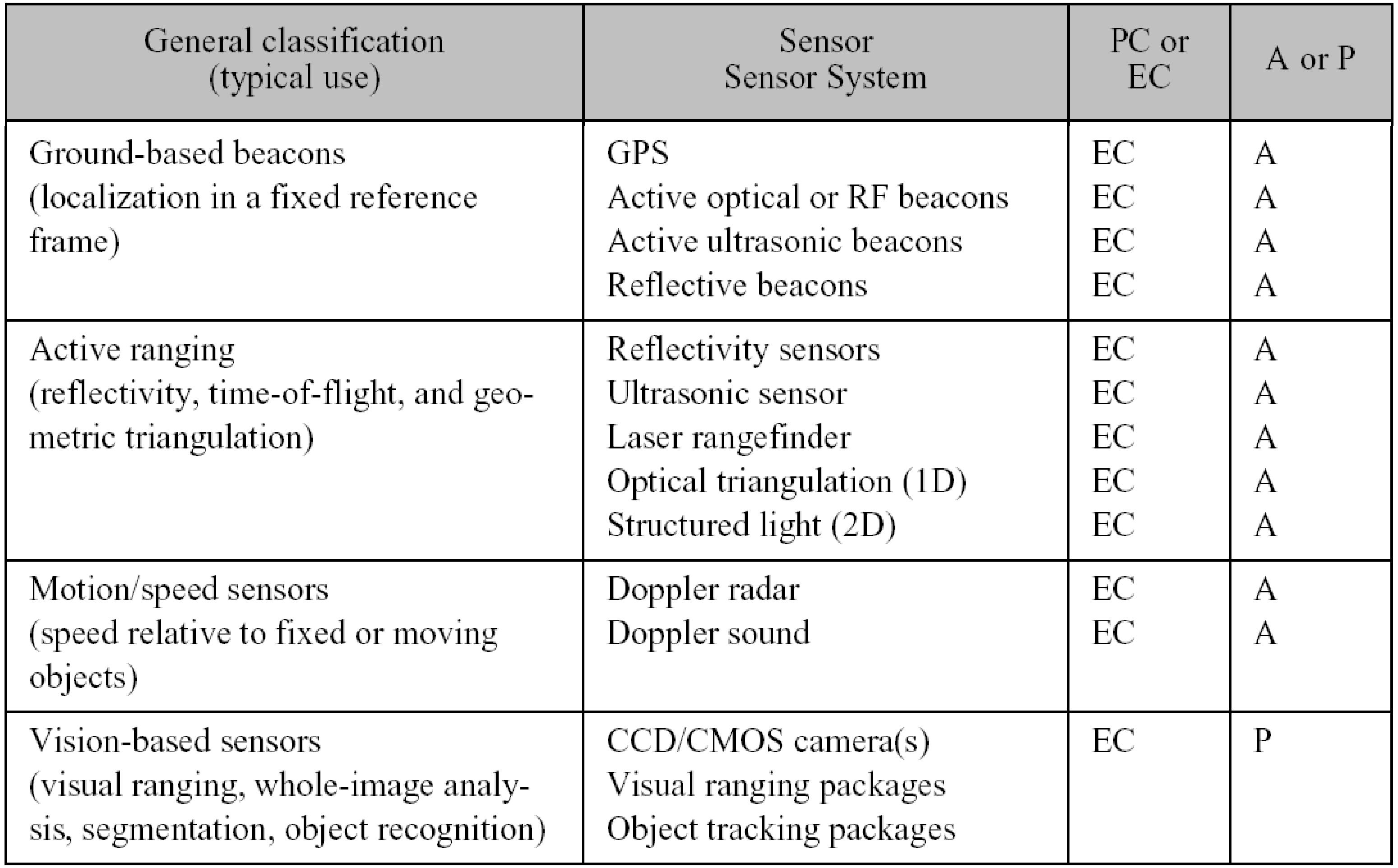
General sensor classification



General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Tactile sensors (detection of physical contact or closeness; security switches)	Contact switches, bumpers	EC	P
	Optical barriers	EC	A
	Noncontact proximity sensors	EC	A
Wheel/motor sensors (wheel/motor speed and position)	Brush encoders	PC	P
	Potentiometers	PC	P
	Synchros, resolvers	PC	A
	Optical encoders	PC	A
	Magnetic encoders	PC	A
	Inductive encoders	PC	A
	Capacitive encoders	PC	A
Heading sensors (orientation of the robot in relation to a fixed reference frame)	Compass	EC	P
	Gyroscopes	PC	P
	Inclinometers	EC	A/P

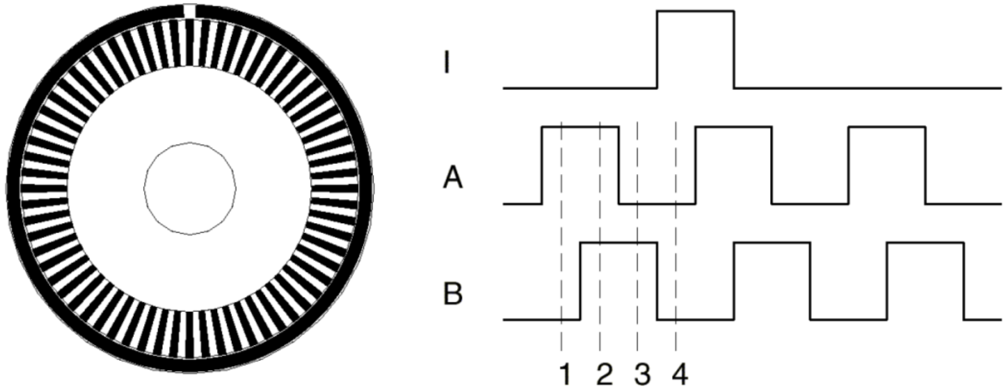
A, active; P, passive; P/A, passive/active; PC, proprioceptive; EC, exteroceptive.

General sensor classification 2



General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Ground-based beacons (localization in a fixed reference frame)	GPS Active optical or RF beacons Active ultrasonic beacons Reflective beacons	EC EC EC EC	A A A A
Active ranging (reflectivity, time-of-flight, and geometric triangulation)	Reflectivity sensors Ultrasonic sensor Laser rangefinder Optical triangulation (1D) Structured light (2D)	EC EC EC EC EC	A A A A A
Motion/speed sensors (speed relative to fixed or moving objects)	Doppler radar Doppler sound	EC EC	A A
Vision-based sensors (visual ranging, whole-image analysis, segmentation, object recognition)	CCD/CMOS camera(s) Visual ranging packages Object tracking packages	EC	P

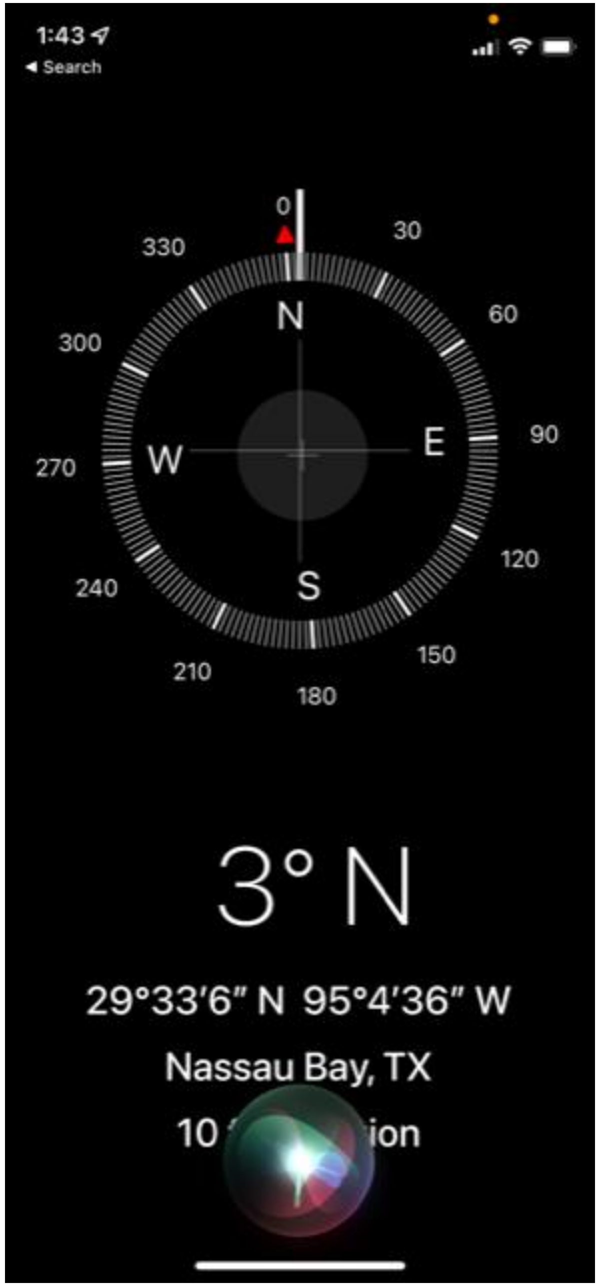
- 1_CS417_IntroductionToRobots_McGill11-Sensors1GoodSlides.pdf
- 2_sensors2CharacteristicsErrors_Niku_AtoD.pdf



State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Fig 4.2 *Quadrature optical wheel encoder: The observed phase relationship between channel A and B pulse trains are used to determine the direction of the rotation. A single slot in the outer track generates a reference (index) pulse per revolution.*

http://www.cs.cmu.edu/~rasc/Download/AMRobots4.pdf



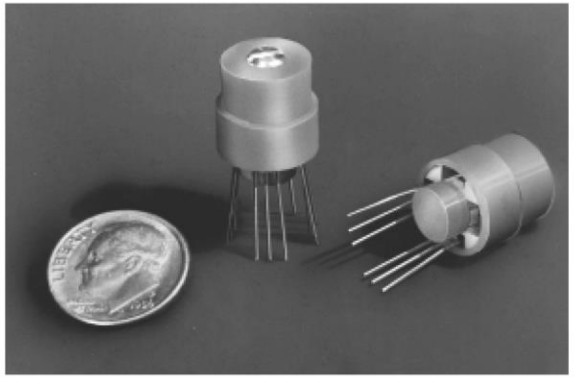


Fig 4.3 *Digital compasses: Sensors such as the Digital/Analog hall effect sensors shown, available from Dinsmore [http://dinsmoregroup.com/dico], enable inexpensive (< $US15) sensing of magnetic fields.*

Important: The accuracy of the compass can be affected by magnetic or environmental interference; even the magnets in the iPhone EarPods can cause a deviation. Use the digital compass only for basic navigation assistance. Don't rely on it to determine precise location, proximity, distance, or direction.

Can Dead Men Vote Twice

C D M V T

C = Compass Heading	291°
D = Deviation	+1
M = Magnetic Heading/Course	290°
V = Varition	5E
T = True Heading/Course	295°

The Sperry Horizon,
Sperry Gyroscope Co.
Brooklyn N.Y.

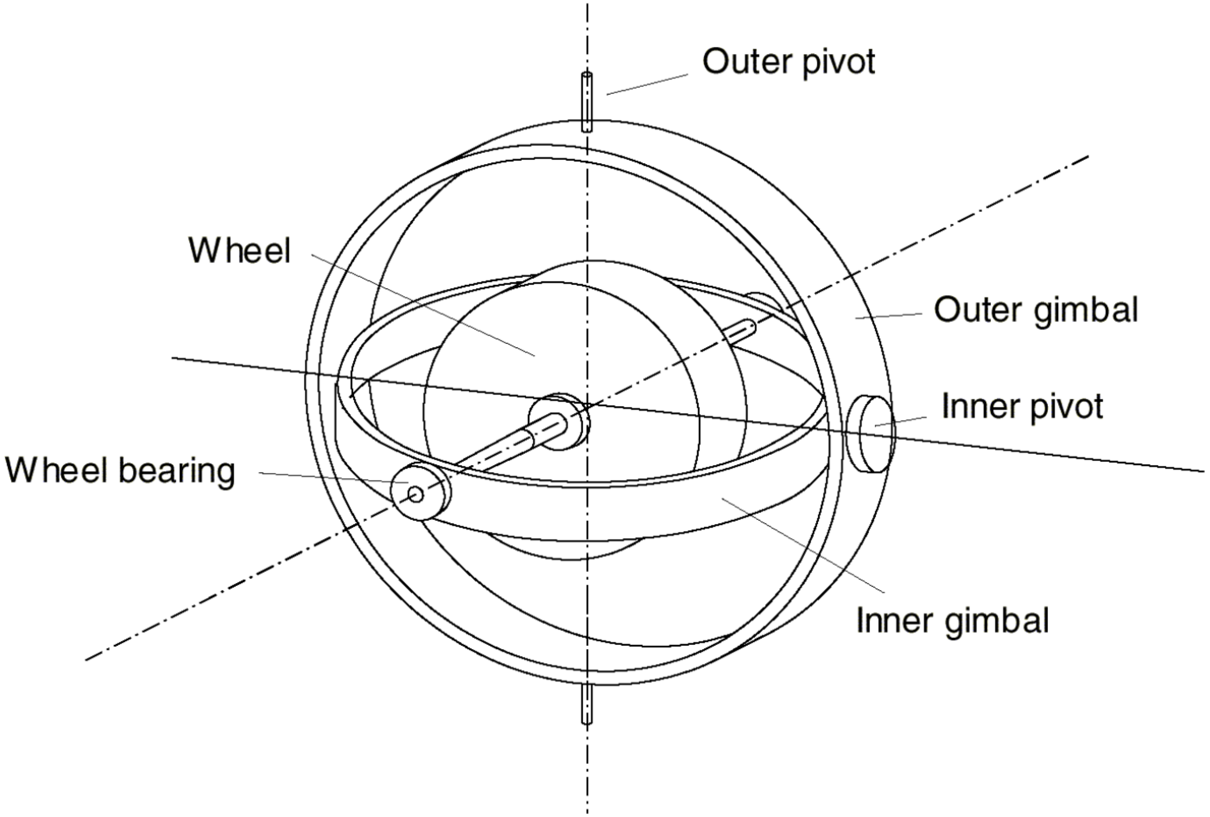


Fig 4.4 *Two axis mechanical gyroscope*

https://www.aceinna.com/newsDetail?id=5f3a8587723b3716e24f89a4&gclid=Cj0KCQiAgP6PBhDmARIsAPWMq6kliVtO--20CXhTEVQstmmQS2t-I5XbahB1077S2UkkkuMOKtJlHAgaArVPEALw_wcB

An IMU with six degrees-of-freedom is composed of multiple inertial MEMS sensors that are temperature compensated and calibrated to align on orthogonal axes. An internal **three-axis gyroscope** capability measures rotation about a known point while a three-axis **accelerometer** measures displacement.

ACEINNA Inc., One Tech Drive, Suite 325, Andover, MA 01810

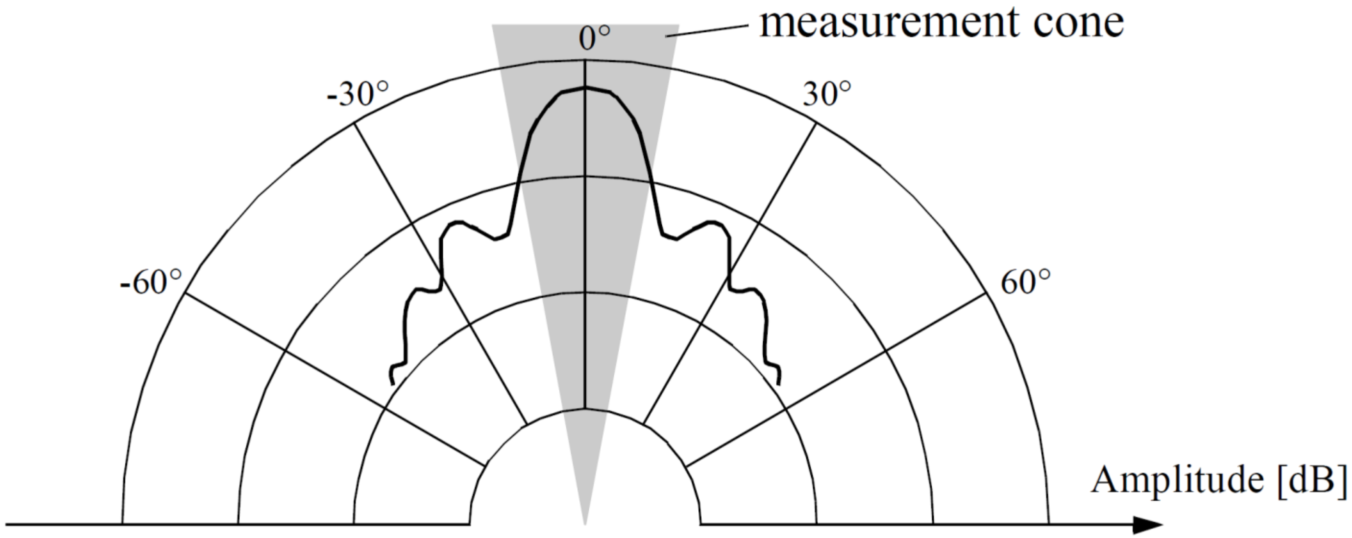
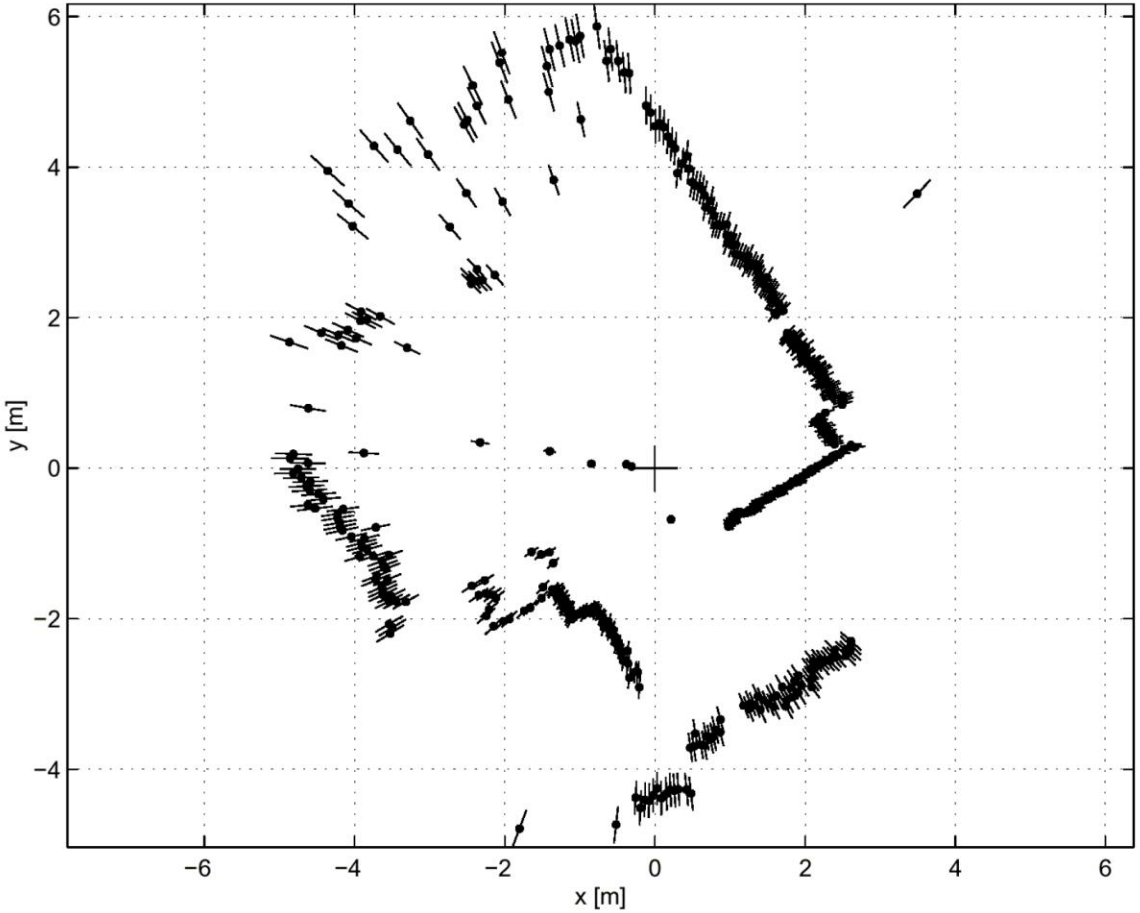
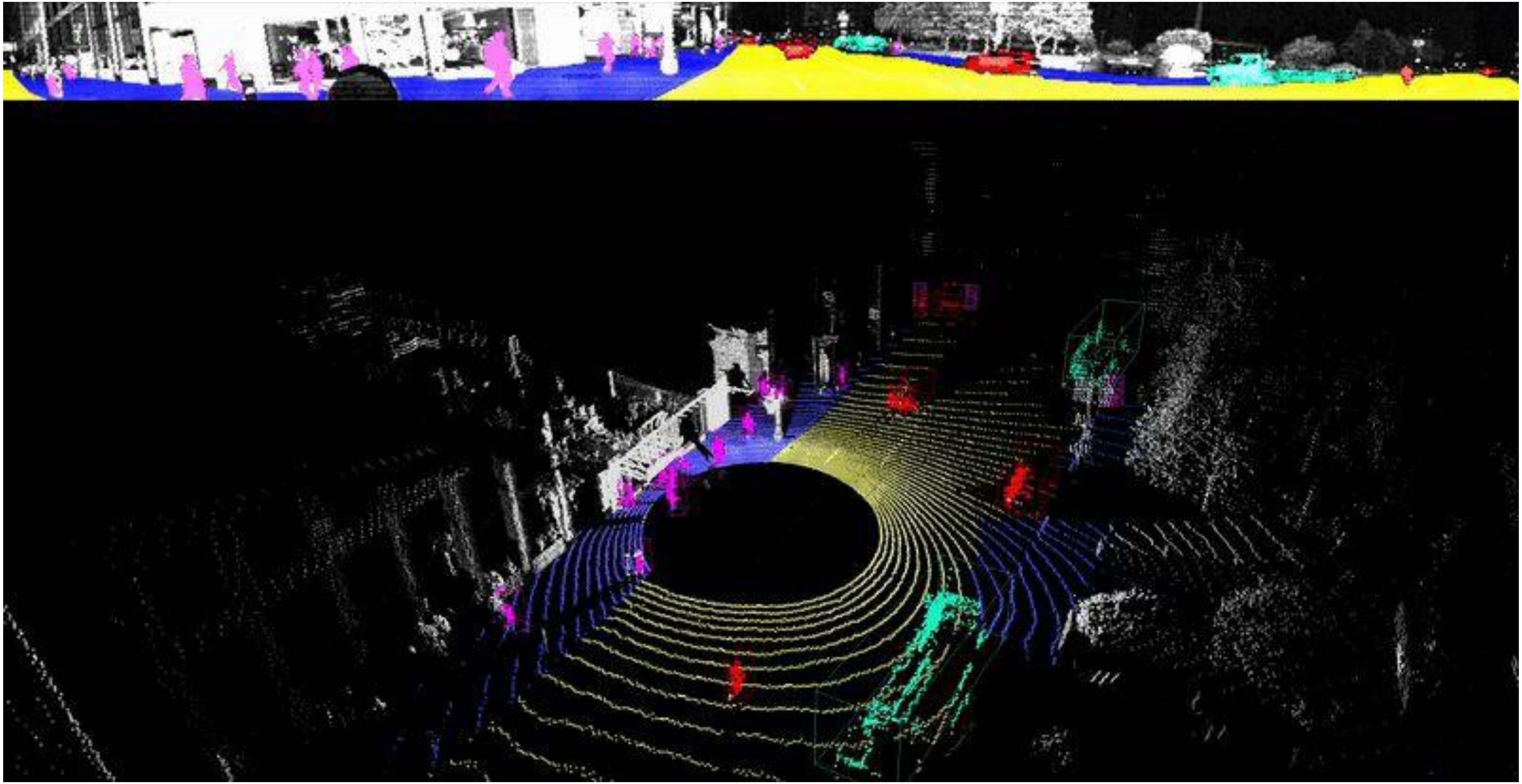


Fig 4.7 *Typical intensity distribution of a ultrasonic sensor*

Fig 4.12

Typical range image of a 2D laser range sensor with a rotating mirror. The length of the lines through the measurement points indicate the uncertainties.





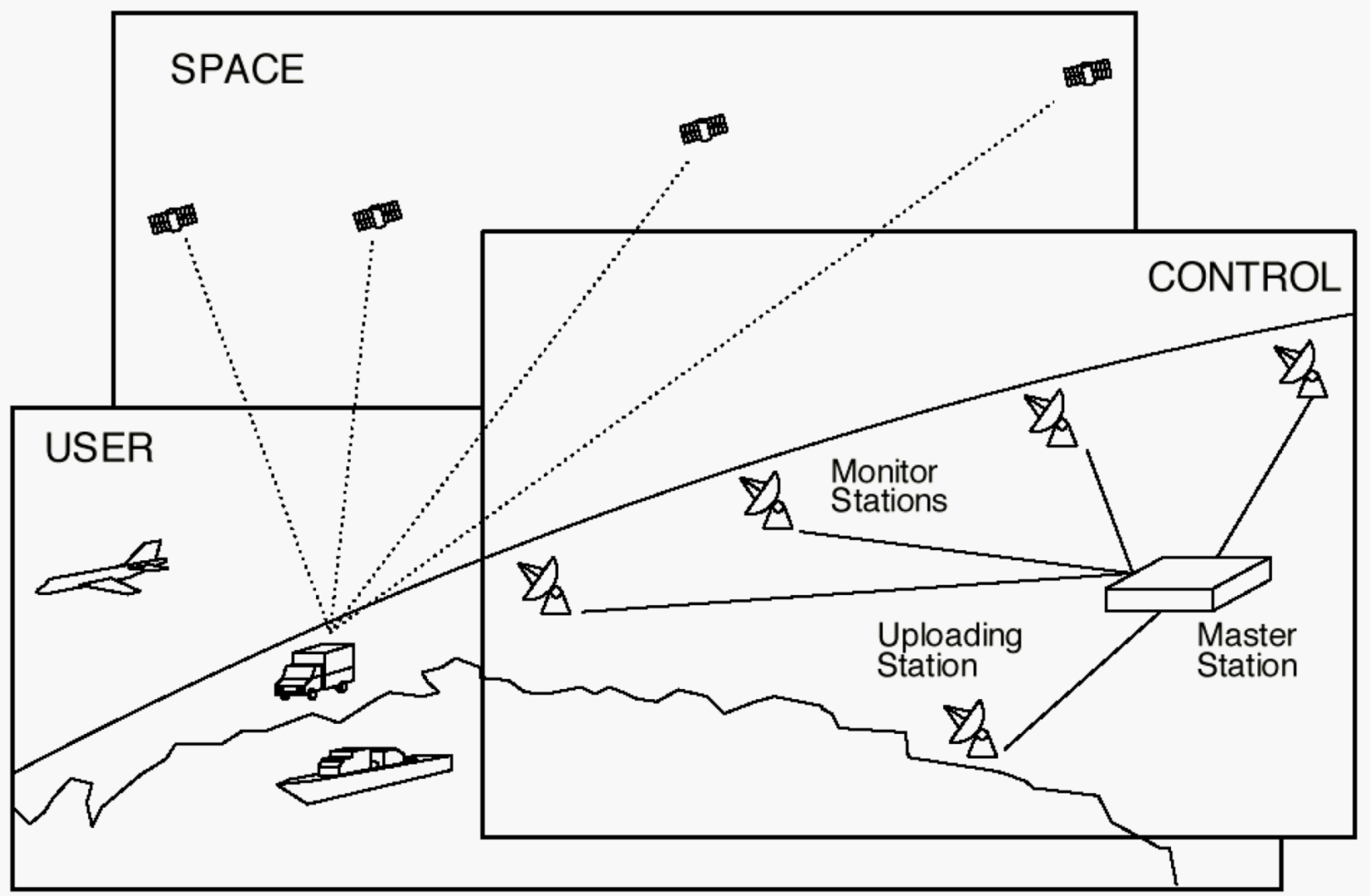
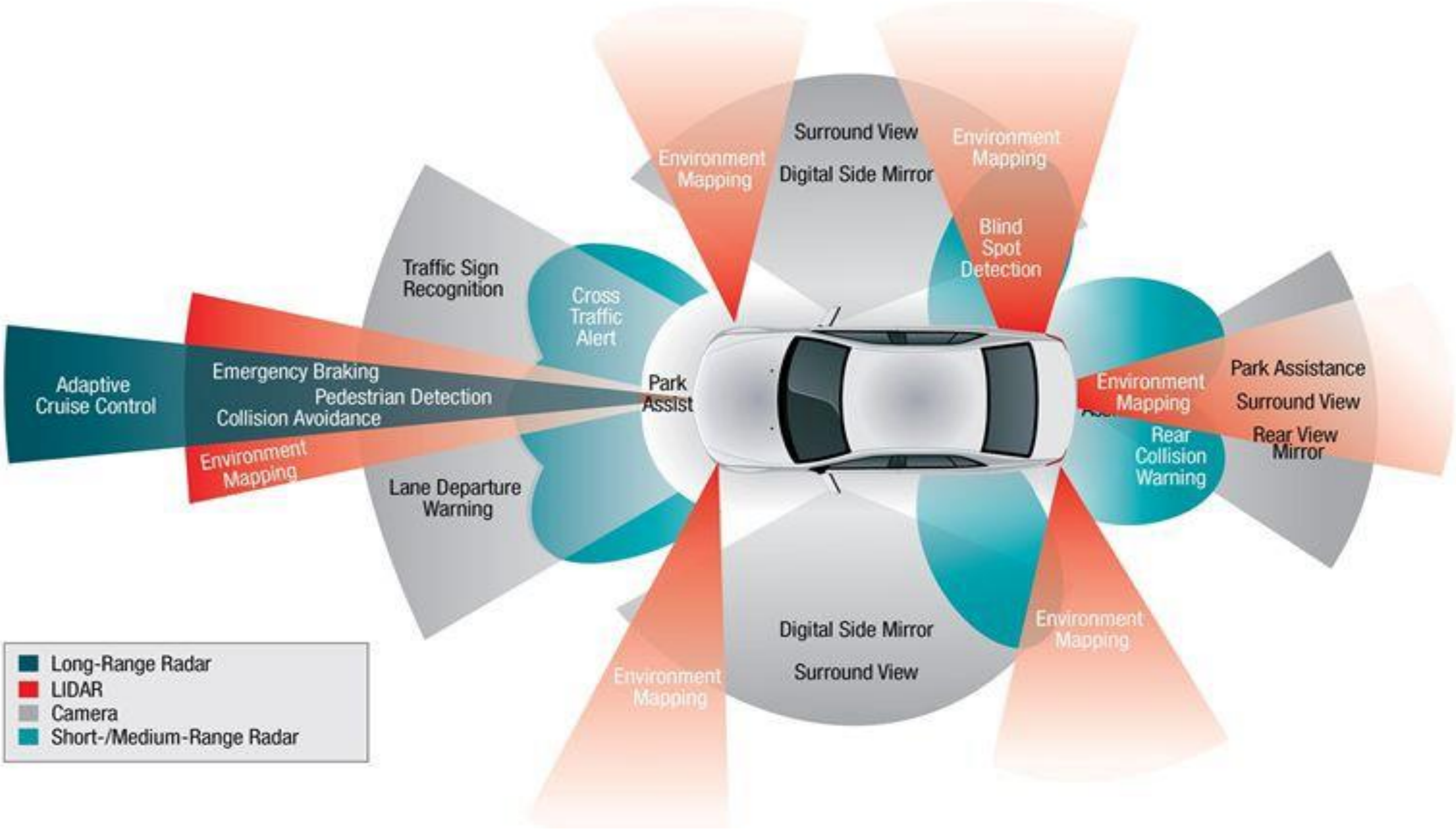


Fig 4.5 Calculation of position and heading based on GPS


Surround View
Digital Side Mirror
Environment Mapping
Environment Mapping
Blind Spot Detection
Traffic Sign Recognition
Cross Traffic Alert
Adaptive Cruise Control
Emergency Braking
Pedestrian Detection
Collision Avoidance
Environment Mapping
Park Assist
Lane Departure Warning
Environment Mapping
Park Assistance
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Digital Side Mirror
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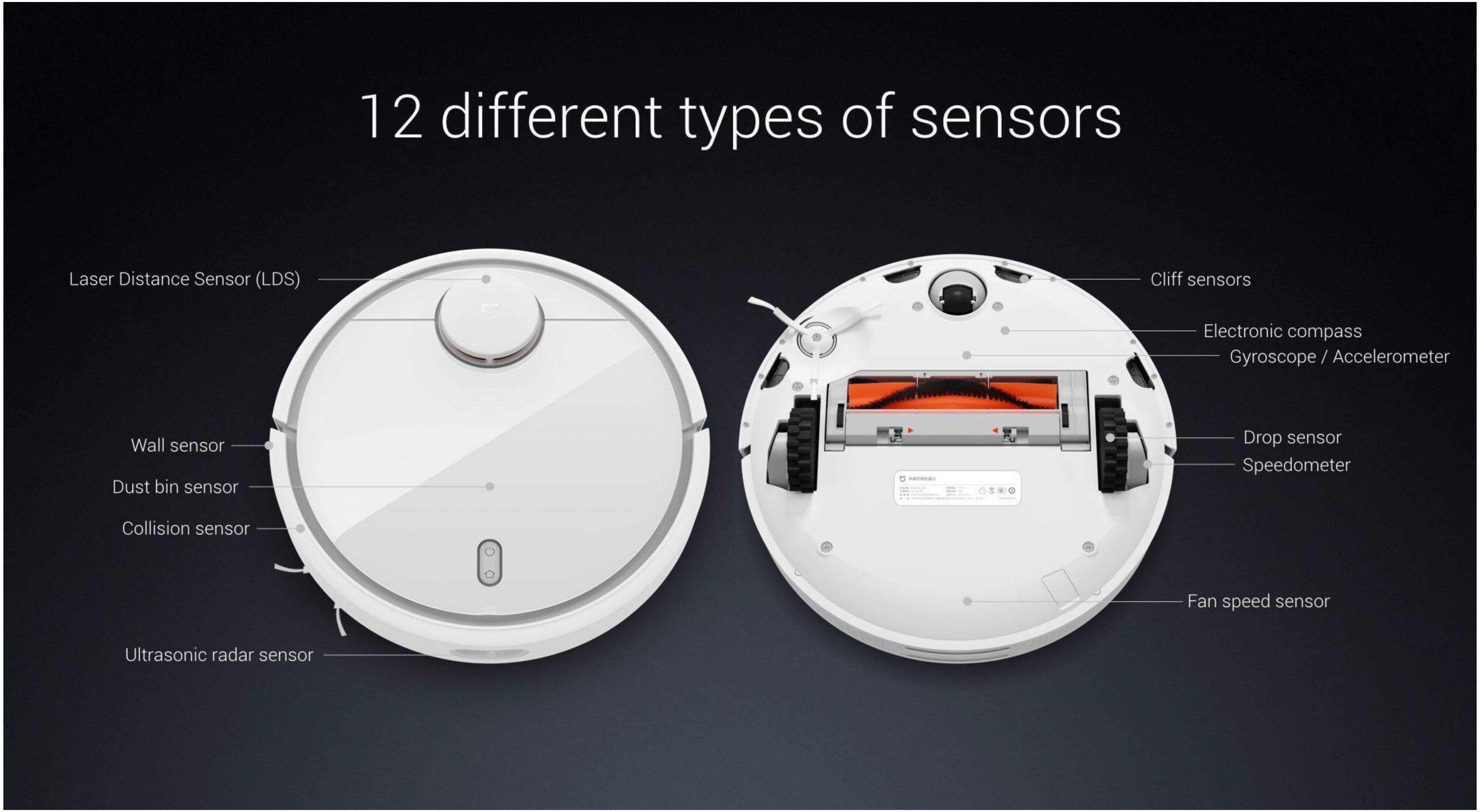
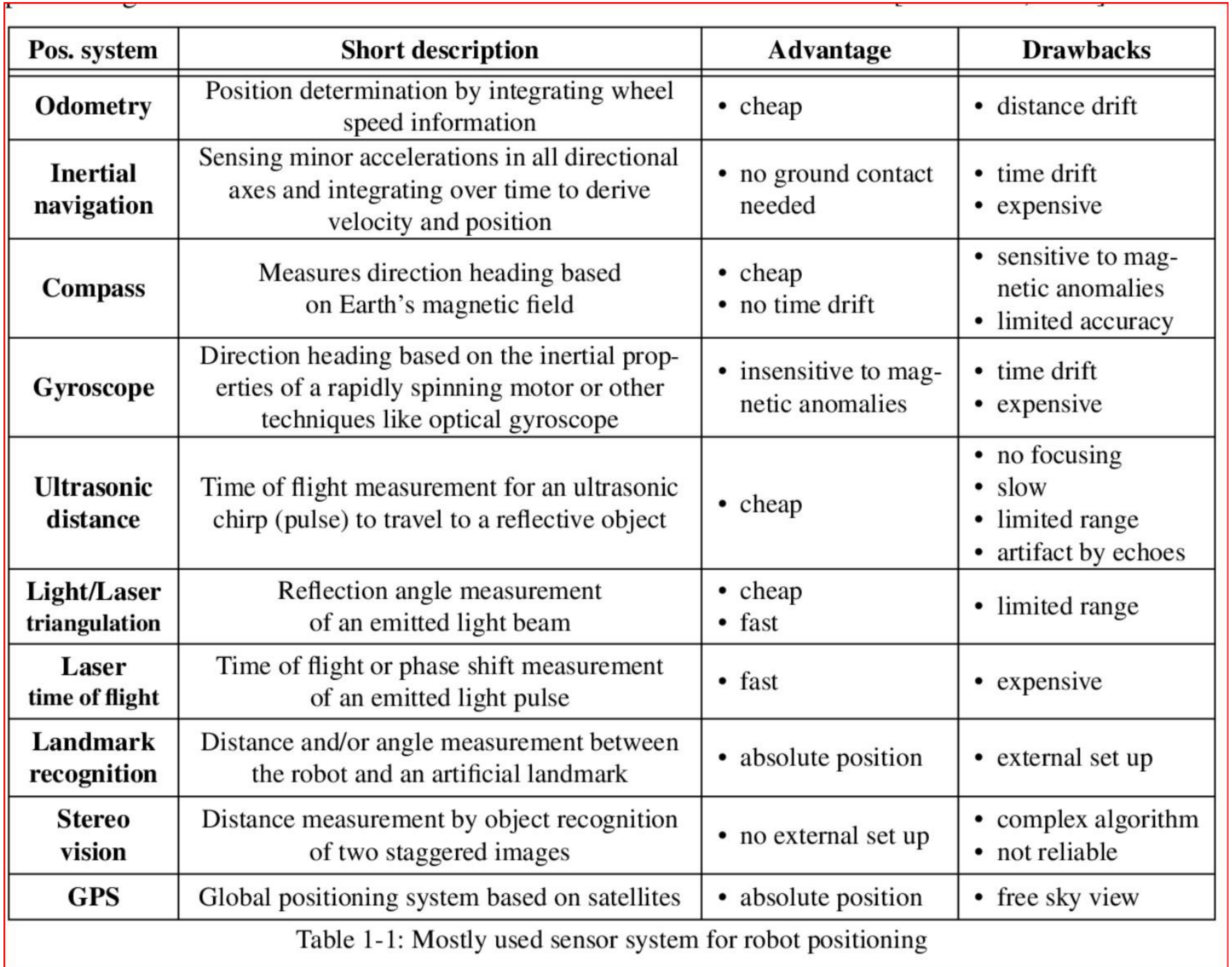
Environment Mapping
Long-Range Radar
LIDAR
Camera
Short-/Medium-Range Radar



My Roomba is pretty smart! Humans have 5 senses ?



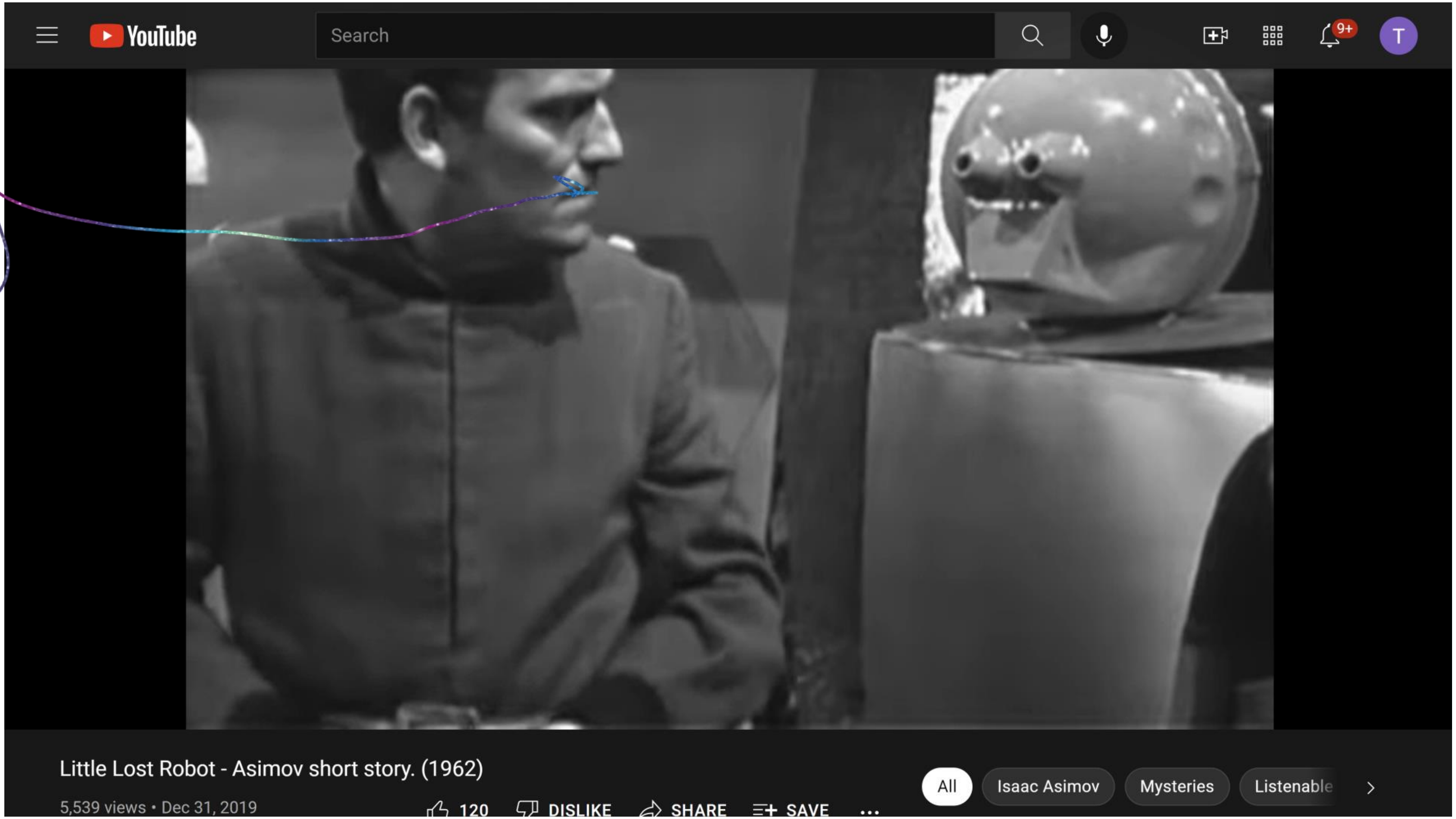
Pos. system	Short description	Advantage	Drawbacks
Odometry	Position determination by integrating wheel speed information	• cheap	• distance drift
Inertial navigation	Sensing minor accelerations in all directional axes and integrating over time to derive velocity and position	• no ground contact needed	• time drift • expensive
Compass	Measures direction heading based on Earth's magnetic field	• cheap • no time drift	• sensitive to magnetic anomalies • limited accuracy
Gyroscope	Direction heading based on the inertial properties of a rapidly spinning motor or other techniques like optical gyroscope	• insensitive to magnetic anomalies	• time drift • expensive
Ultrasonic distance	Time of flight measurement for an ultrasonic chirp (pulse) to travel to a reflective object	• cheap	• no focusing • slow • limited range • artifact by echoes
Light/Laser triangulation	Reflection angle measurement of an emitted light beam	• cheap • fast	• limited range
Laser time of flight	Time of flight or phase shift measurement of an emitted light pulse	• fast	• expensive
Landmark recognition	Distance and/or angle measurement between the robot and an artificial landmark	• absolute position	• external set up
Stereo vision	Distance measurement by object recognition of two staggered images	• no external set up	• complex algorithm • not reliable
GPS	Global positioning system based on satellites	• absolute position	• free sky view

Table 1-1: Mostly used sensor system for robot positioning

Jonny 5 - WHERE AM I?

"**Little Lost Robot**" is a science fiction short story by American writer Isaac Asimov. It was first published in the March 1947 issue of *Astounding Science Fiction* and reprinted in the collections *I, Robot* (1950), *The Complete Robot* (1982), *Robot Dreams* (1986), and *Robot Visions* (1990).

GET LOST



Little Lost Robot - Asimov short story. (1962)

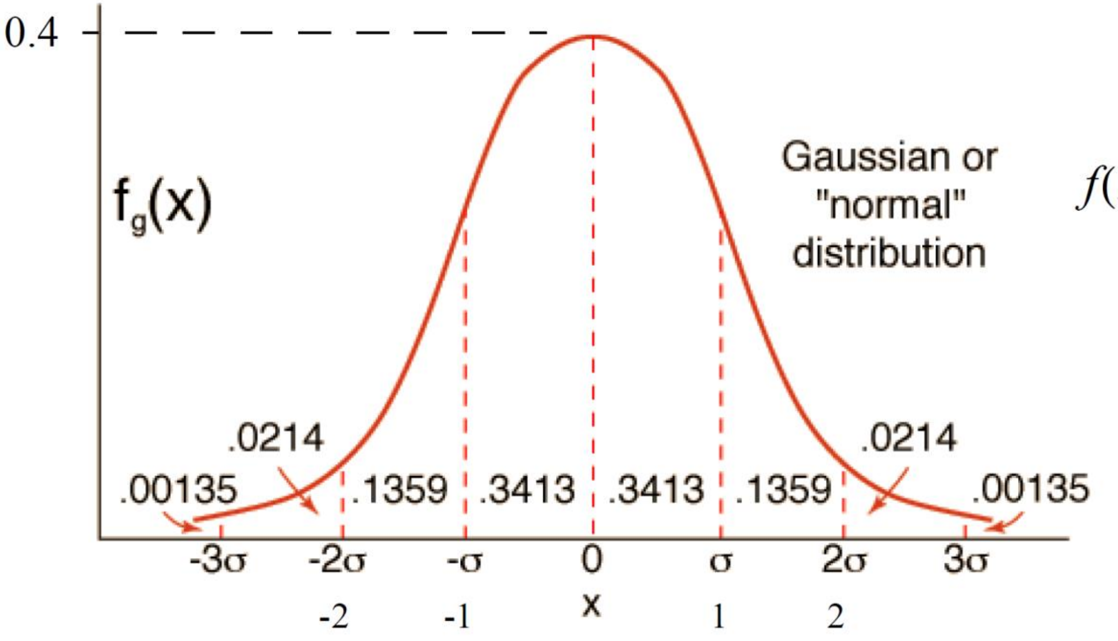
5,539 views • Dec 31, 2019

https://www.youtube.com/watch?v=I-RX1GT4GT0

The quality of time-of-flight range sensors depends mainly on:

- Uncertainties in determining the exact time of arrival of the reflected signal
- Inaccuracies in the time of flight measurement (particularly with laser range sensors)
- The dispersal cone of the transmitted beam (mainly with ultrasonic range sensors)
- Interaction with the target (e.g. surface absorption, specular reflections)
- Variation of propagation speed
- The speed of the mobile robot and target (in the case of a dynamic target)

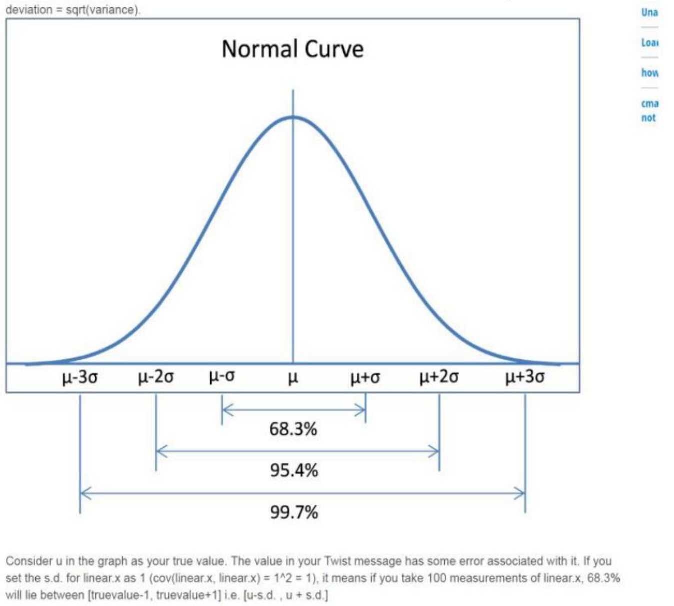
As discussed below, each type of time-of-flight sensor is sensitive to a particular subset of the above list of factors.



$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

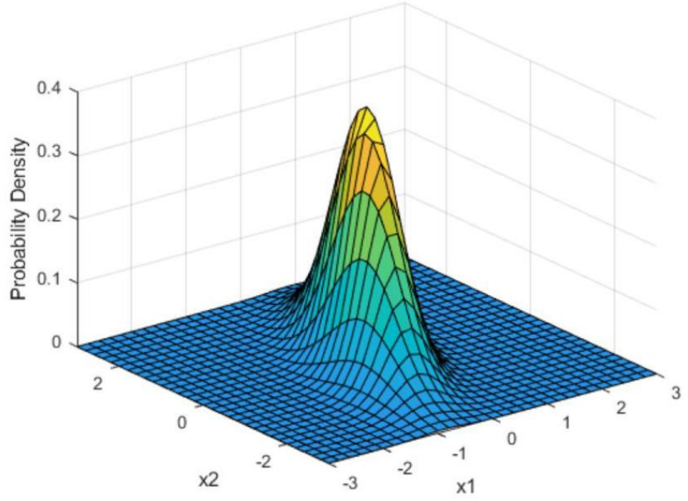
Fig 4.31 *The Gaussian function with* $\mu = 0$ and $\sigma = 1$. We shall refer to this as the Reference Gaussian. The value 2σ is often refereed for the signal quality. 95.44% of the values are falling within $\pm 2\sigma$.

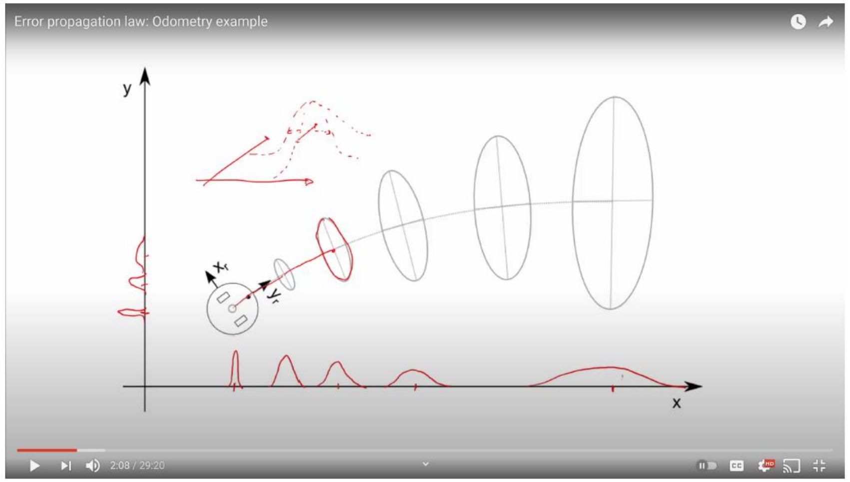
Odometry Errors & Variance & Covariance

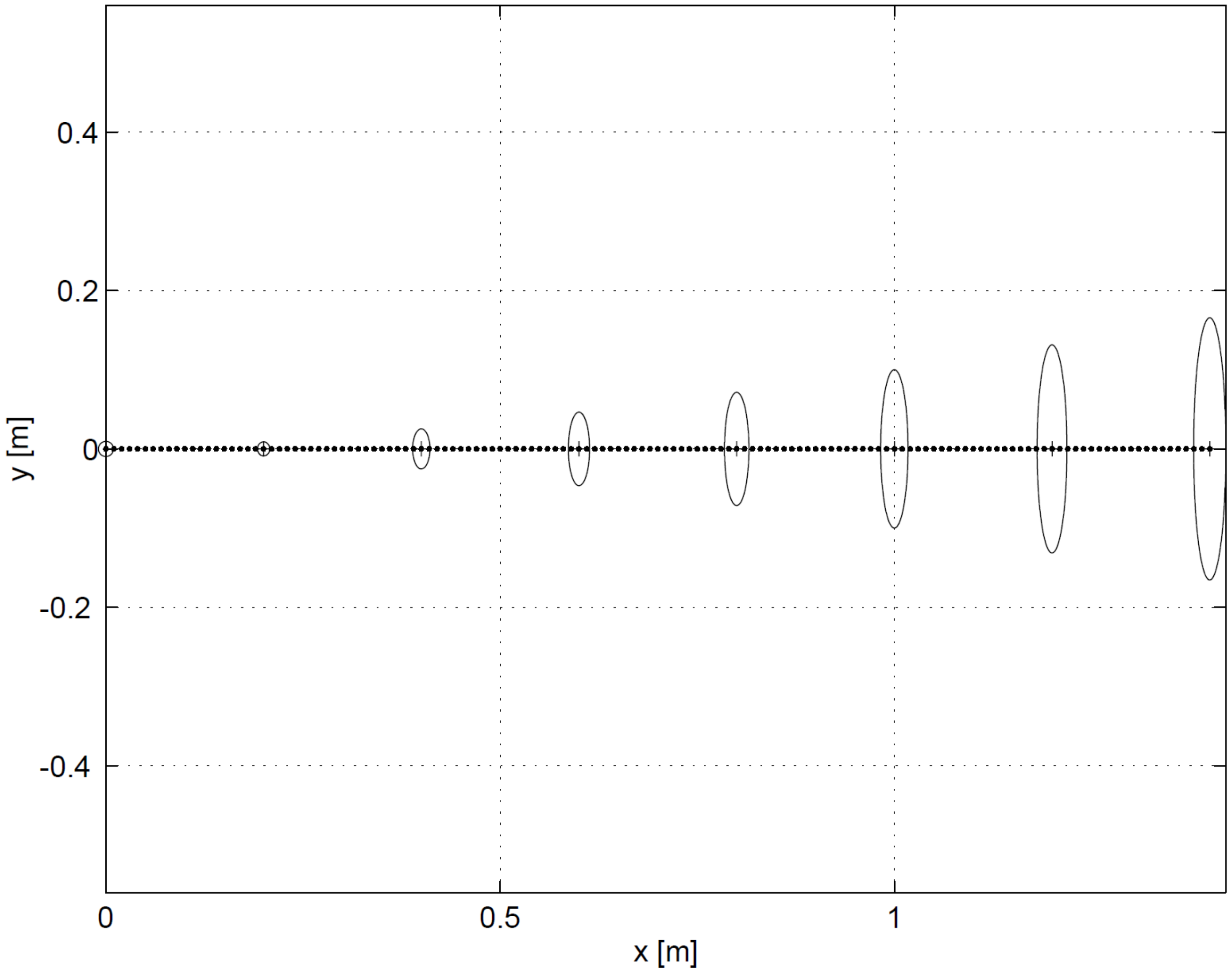


deviation = sqrt(variance).

Consider u in the graph as your true value. The value in your Twist message has some error associated with it. If you set the s.d. for linear.x as 1 (cov(linear.x, linear.x) = 1^2 = 1), it means if you take 100 measurements of linear.x, 68.3% will lie between [truevalue-1, truevalue+1] i.e. [u-s.d. , u + s.d.]







Growth of the pose uncertainty for straight line movement: No

http://www.cs.cmu.edu/~rasc/Download/AMRobots5.pdf