Development of intelligent systems (RInS)

Robot sensors and TurtleBot

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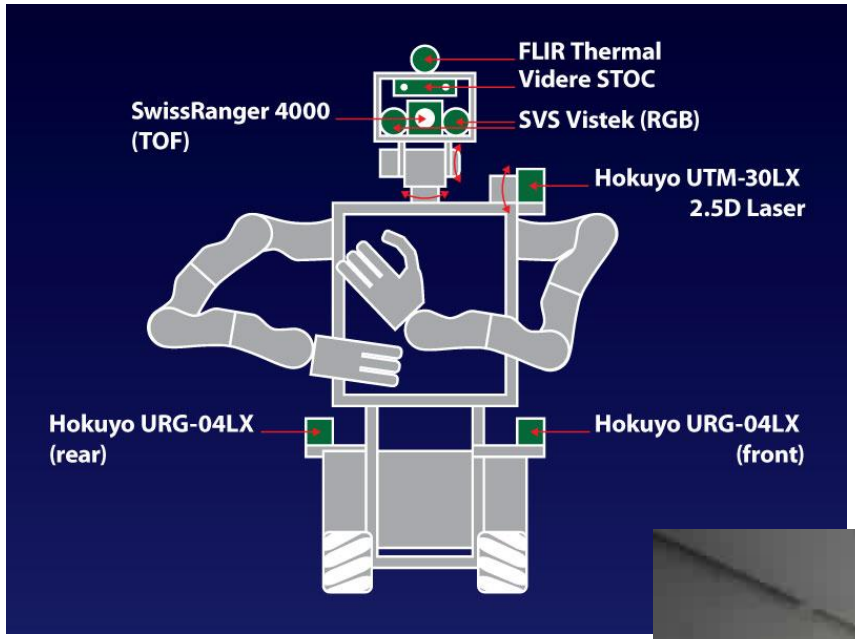
Academic year: 2024/25

Robotic sensors



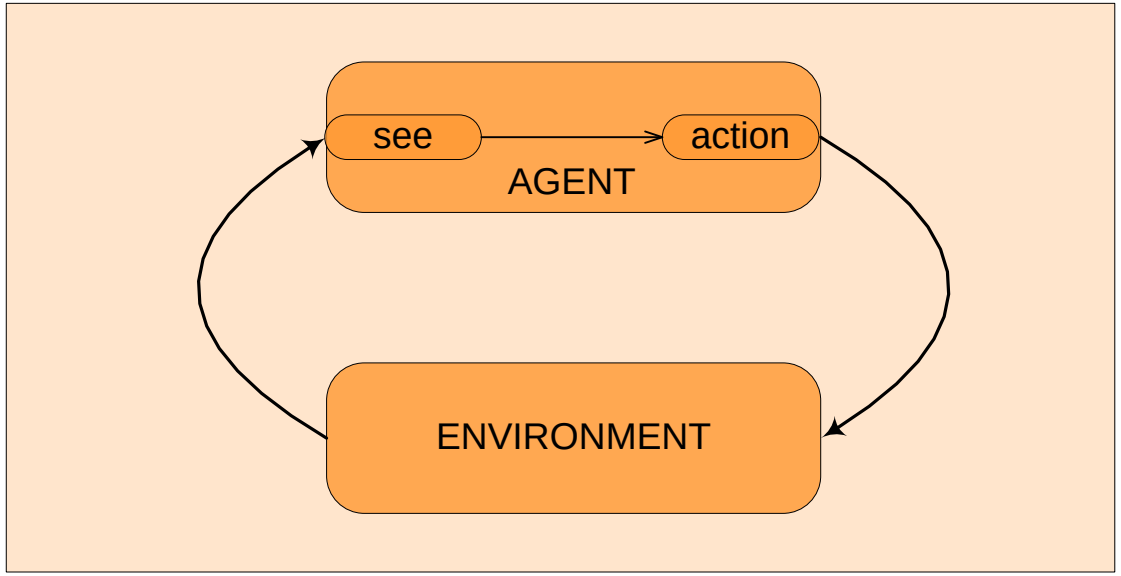
Sensors

Robot platforms

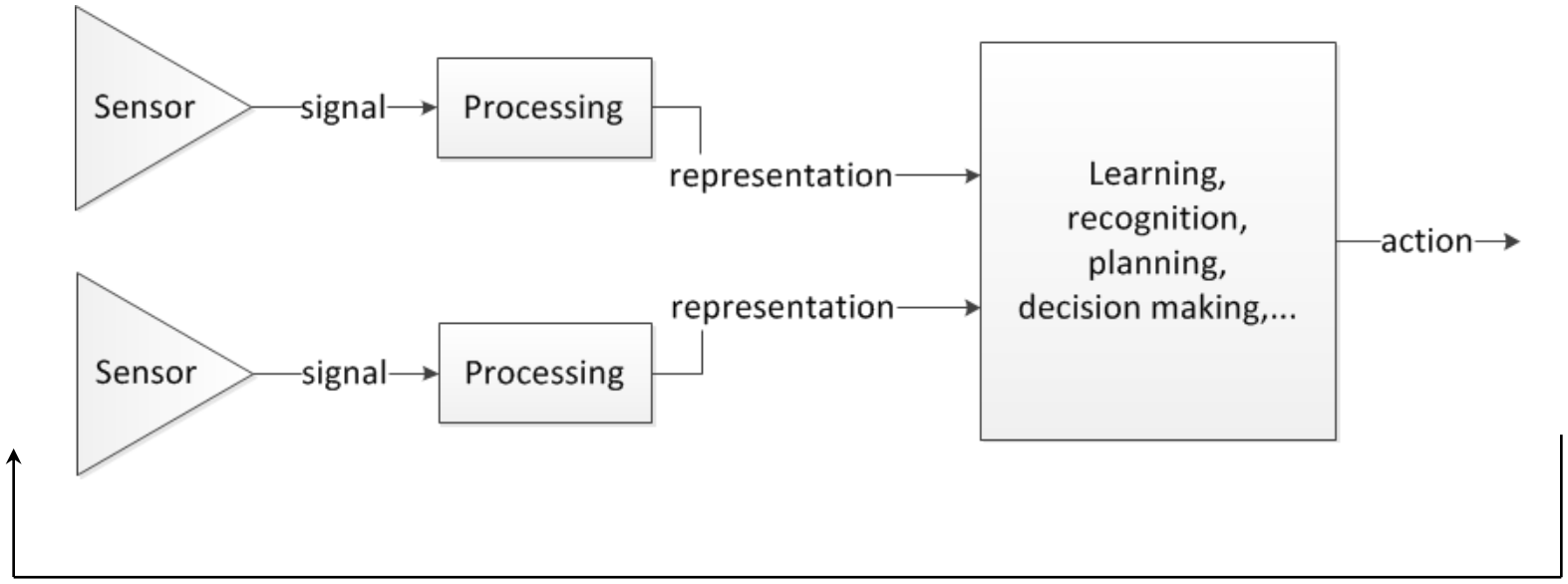
http://ias.cs.tum.edu

Sensors

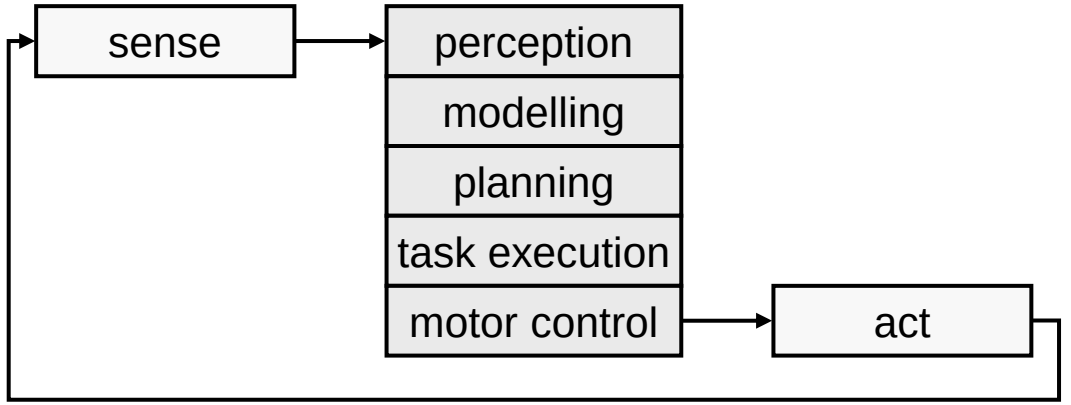
- Equivalent to human senses
- Acquire information from the environment
- Electronic/mechanic/chemical device that maps the attributes of the environment into a quantitative measurement
- Robot can differentiate only between the states in the environment, which can be sensed differently



Perception action cycle



- Significant abstraction of the real world



Senses

- Human senses:

- The list of robot senses is much longer!
  - Beyond human capabilities
  - Vision beyond visual spectrum (IR cameras, etc.)
  - Active vision (radar, LIDAR)
  - Hearing beyond the range 20 Hz-20 kHz (ultrasound)
  - Chemical analysis for better taste and smell
  - Measurement of temperature, humidity, illumination, radiation, pressure, volume, position, direction, acceleration, velocity, etc.

Classification of sensors

- Proprioceptive and exteroceptive sensors
  - Proprioceptive: measure internal states of the robot (batter status, position of wheels, angle between the segments in the robot arm)
  - Exteroceptive: measure the state of the environment (majority of the sensors)
- Passive and active sensors
  - Passive: only receive the energy from the environment (e.g., camera)
  - Active: also emit the energy in the environment (e.g., radar)
- Noninvasive and invasive sensors
  - Noninvasive (contactless): no contact with the object
  - Invasive: measurement with contact
- Visual, non-visual

Classification of sensors

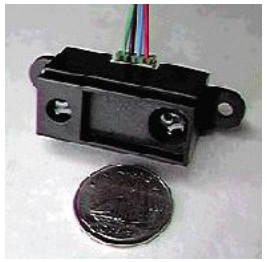
General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Tactile sensors (detection of physical contact or closeness; security switches)	Contact switches, bumpers	EC	P
	Optical barriers	EC	A
	Noncontact proximity sensors	EC	A
Wheel/motor sensors (wheel/motor speed and position)	Brush 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.

Classification of sensors

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

Sensors in robots


Digital Infrared Ranging


CDS Cell
Resistive Light Sensor


Piezo Bend Sensor


Pendulum Resistive
Tilt Sensors

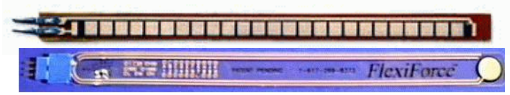

Metal Detector


Gas Sensor

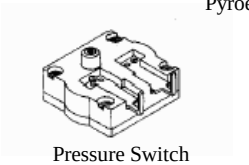

Gieger-Muller
Radiation Sensor

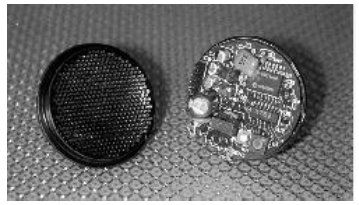

UV Detector


Pyroelectric Detector



Resistive Bend Sensors


Pressure Switch

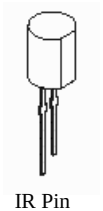

Miniature Polaroid Sensor

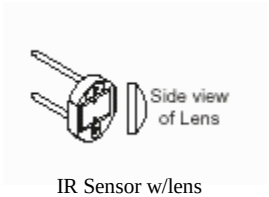

Limit Switch


Mechanical Tilt Sensors

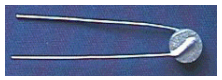

Touch Switch


Gyro


IR Pin
Diode



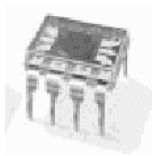
IR Sensor w/lens


Thyristor

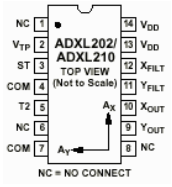

Magnetic Sensor


Polaroid Sensor Board


IR Reflection
Sensor

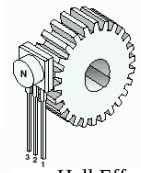

IR Amplifier Sensor

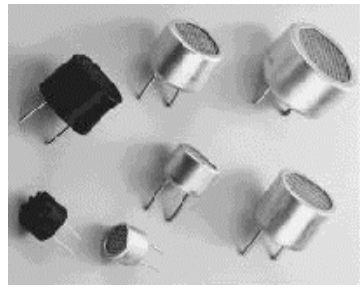

IRDA Transceiver

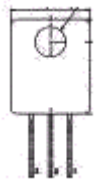


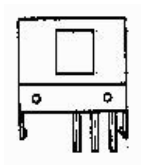
Accelerometer

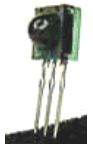

Magnetic Reed Switch


Hall Effect
Magnetic Field
Sensors

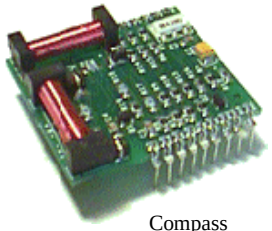

Piezo Ultrasonic Transducers

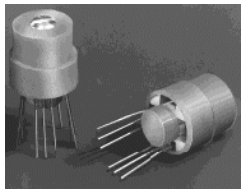

Lite-On IR
Remote Receiver


Radio Shack
Remote Receiver


IR Modulator
Receiver

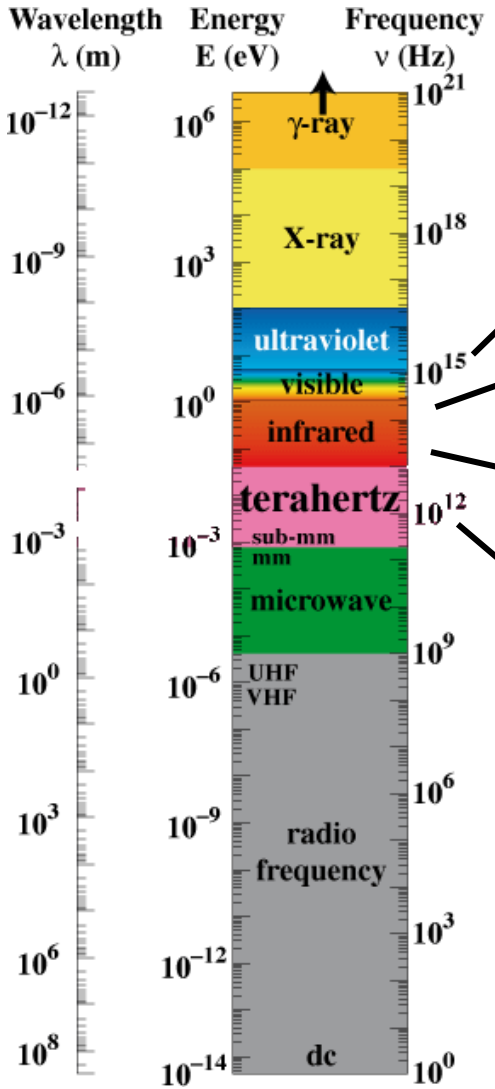

Solar Cell


Compass


Compass

Cameras

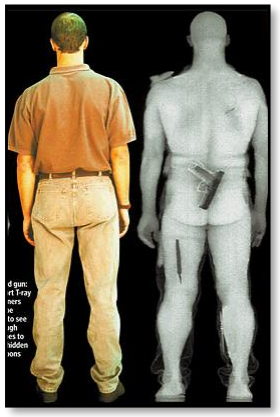
Electromagnetic spectrum



Visual
"light"

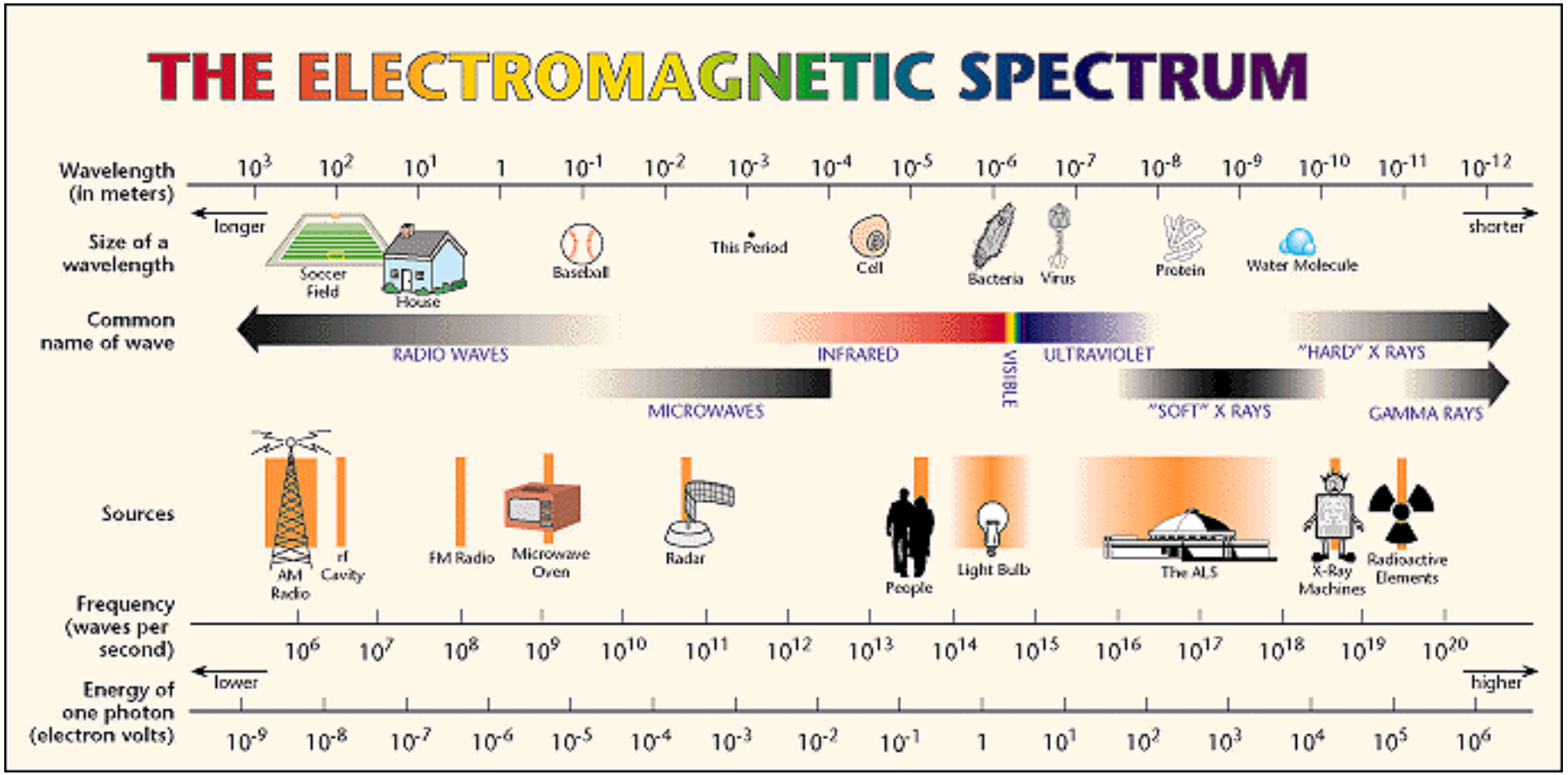
Near infrared
"light"
(NIR)

Long-wavelength
infrared "light"
(FLIR)



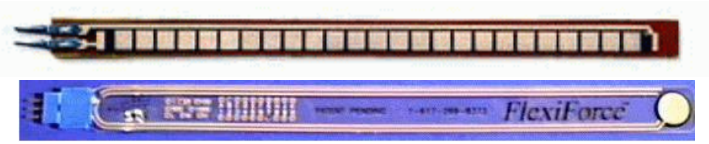
Terahertz
"light"
(T-ray)

Sensing EM radiation



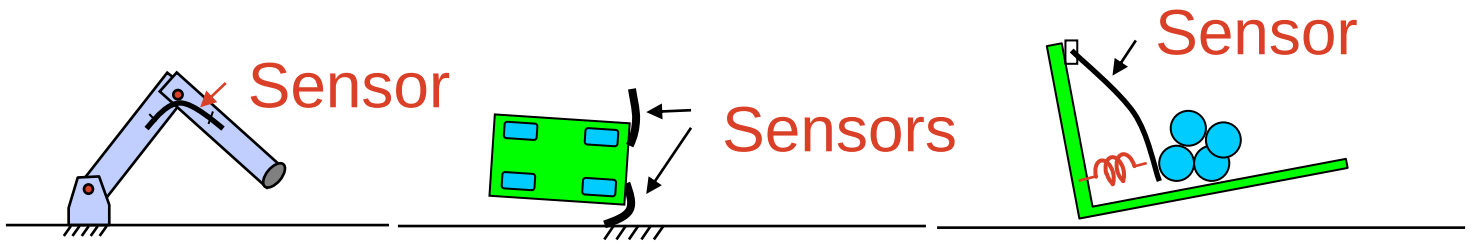
Resistive sensors

- Band sensor
  - The resistance changes by bending the sensor



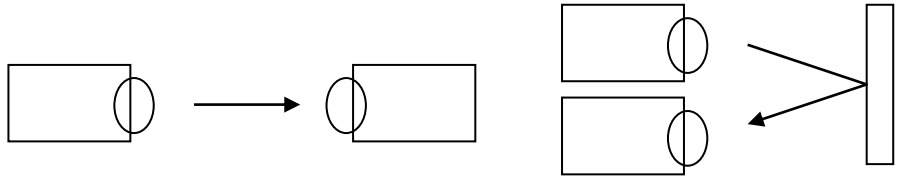
- Potentiometer
  - Position sensor in sliding or rotating mechanisms

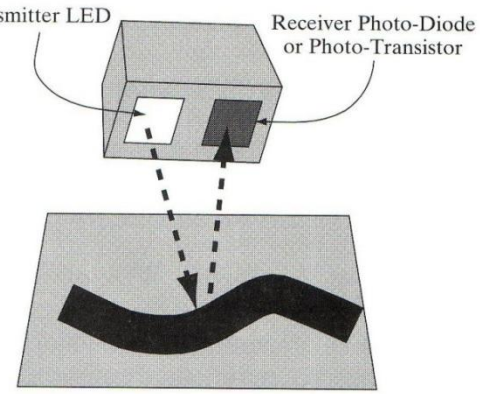
- Photoresistor
  - Small resistance at high illumination
  - Light detection



Infrared sensors

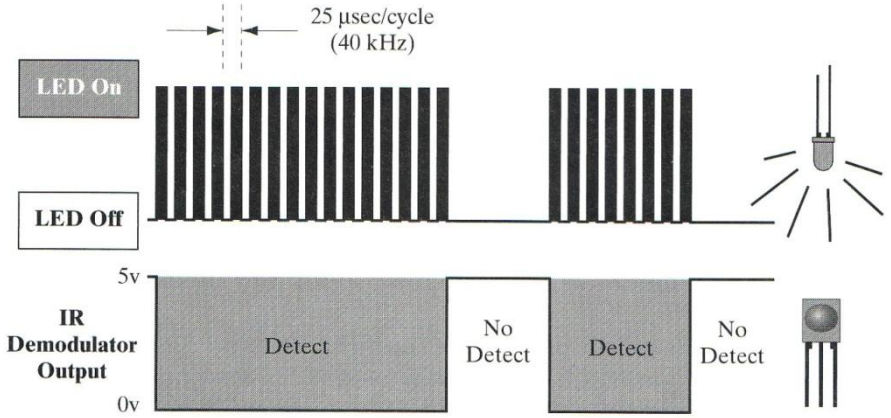
- Intensity IR sensors
  - Emit an receive IR light
  - Photo-transistor





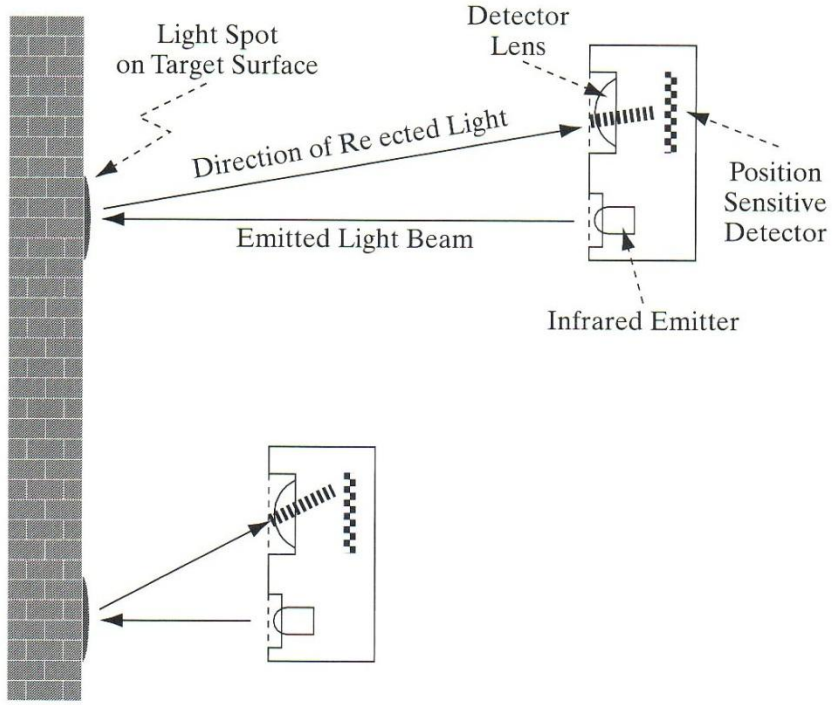
  - Sensitive on daylight, reflections, distance
  - Robust, cheap
  - Application: object detection, optical encoder

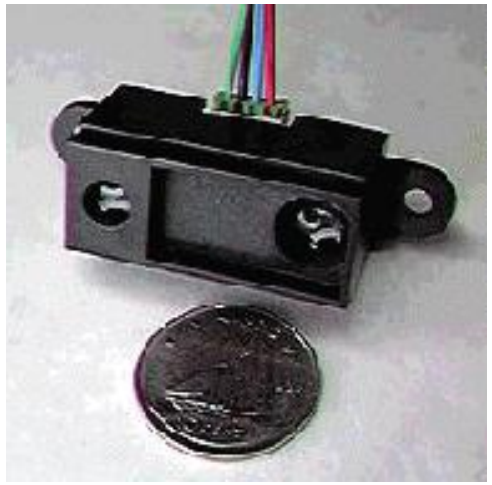
- Modulated IR sensors
  - Modulation in demodulation
  - Pulse detection
  - More robust
  - IR remotes, itn.



Infrared sensors

- Range sensors
- Measuring angle between the emitted and received light
  -> triangulation

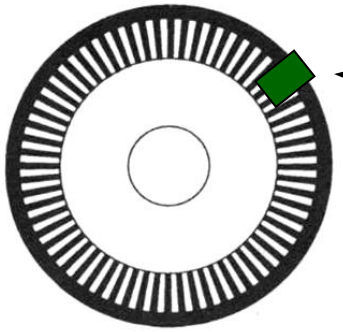


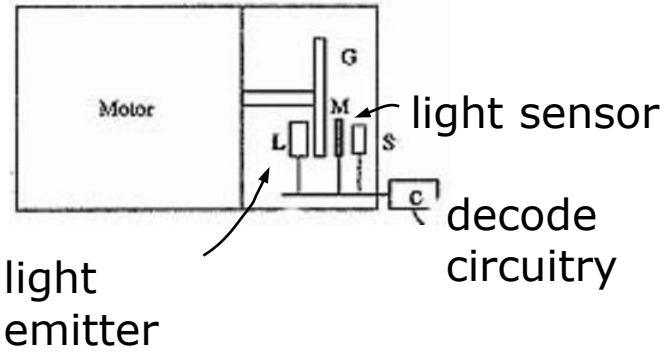


- Non-sensitive on ambient light

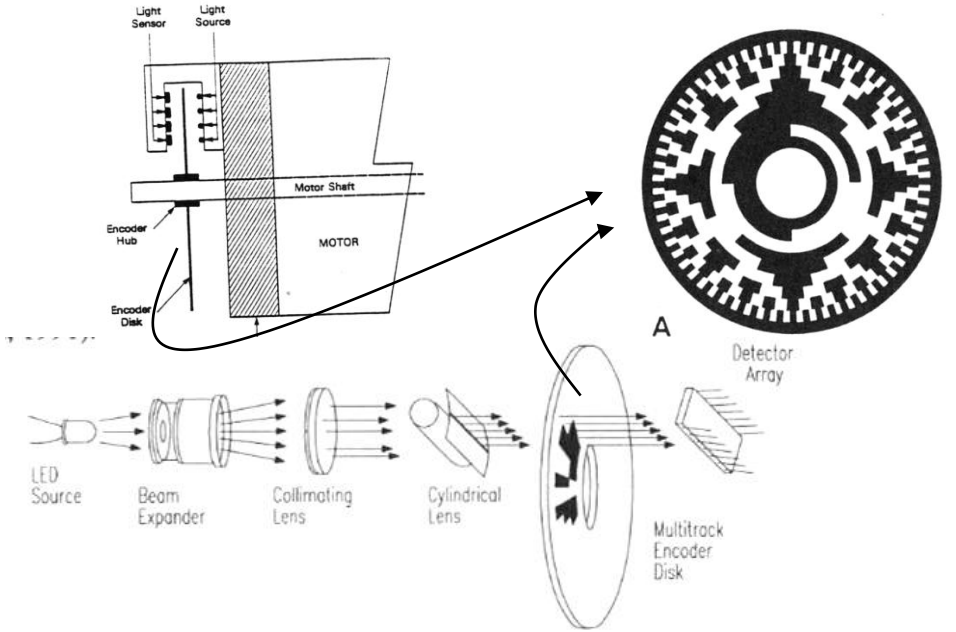
Measuring rotation

- Incremental Optical Encoders
  - Relative rotation



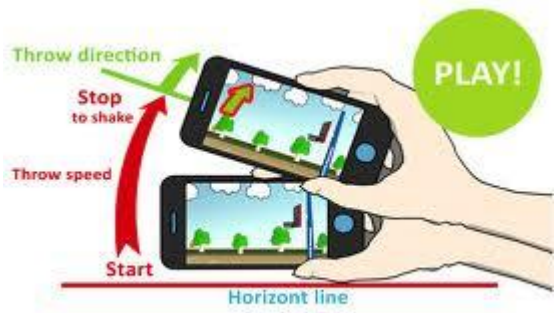


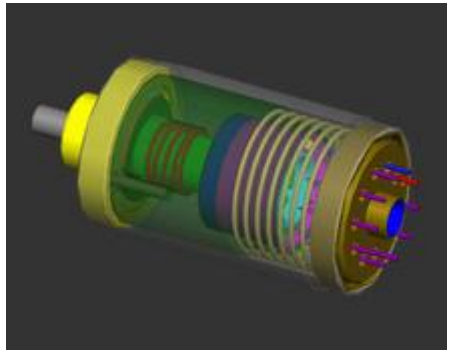
- Incremental Optical Encoders
- Absolute position
  - Gray code



Inertial sensors

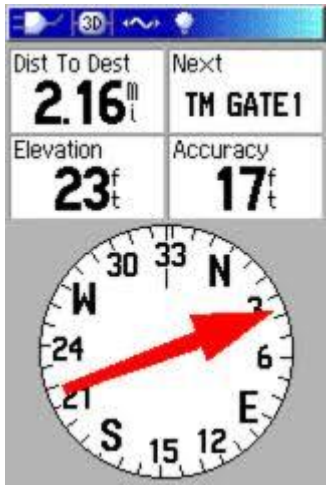
- Gyroscope
  - Measuring change of orientation
  - based on the principles of angular momentum
- Accelerometer
  - Measures acceleration, also orientation
  - Uniaxial, triaxial
  - Vibration sensor, vibration analysis, detection of orientation
  - Nintendo Wii, smart phones





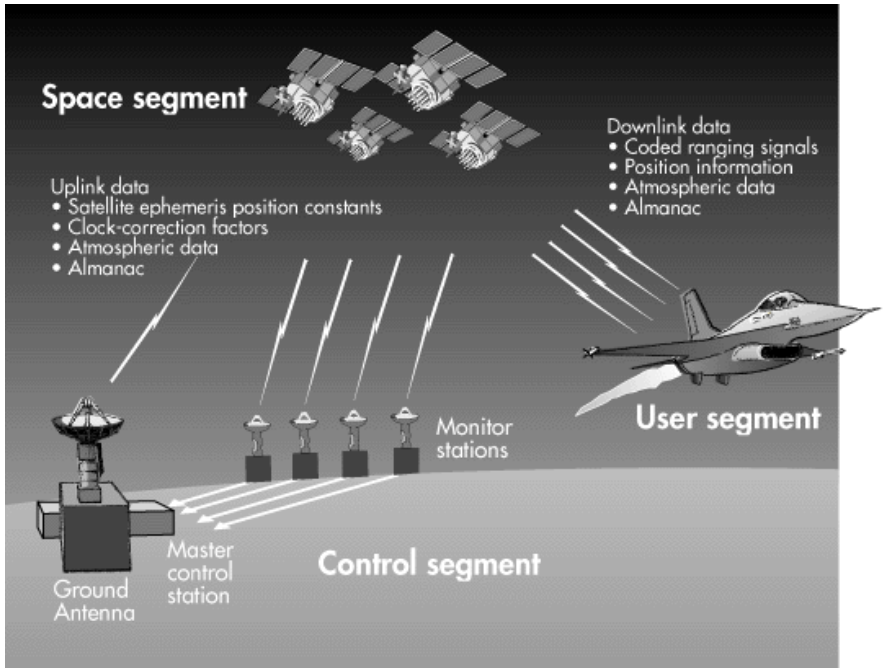
Compass

- Electronic compass
- Absolute orientation of the robot
  - N, S, E, W



GPS

- Global Positioning System
- 24 satellites at the height of 20200 km
- Atomic clock
- Satellite emit the time and position data
- At least 4 satellites should be visible
- Differential GPS – additional (terrestrial) signals are considered



Tactile sensors

- Haptic technology
- Buttons, switches
- Bumpers (collision sensors)
- Touch sensors on the robot arm
- Different types:
  - Piezoresistive
  - Piezoelectric
  - Capacitive
  - Elastoresistive
- Artificial skin

Acustic sensors

- Perception of sound

- Sonar

- Microphone
  - Array of microphones
  - Detection the sound direction

Range sensors

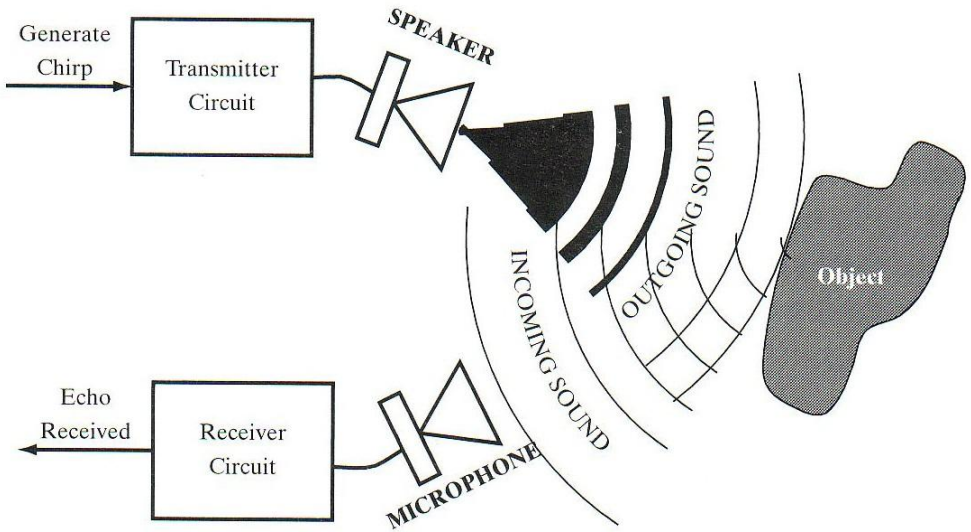
- Stereo vision
- Shape from X
- Coded light range sensor

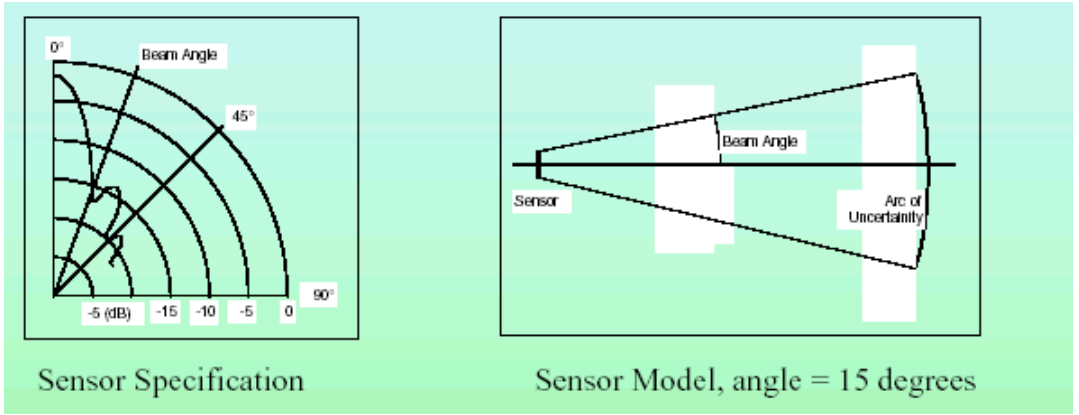
- IR range sensor

- Time Of Flight sensors
  - Emit the signal, wait until it is back, measure the time
  - RADAR
  - SONAR
  - LIDAR
  - ToF cameras

Sonar

- Emits ultrasound
- Measure the time
- Bat, dolphin
- From a couple of cm to 30 m
- 30 degrees angular accuracy
- Quite slow: 200ms for 30m



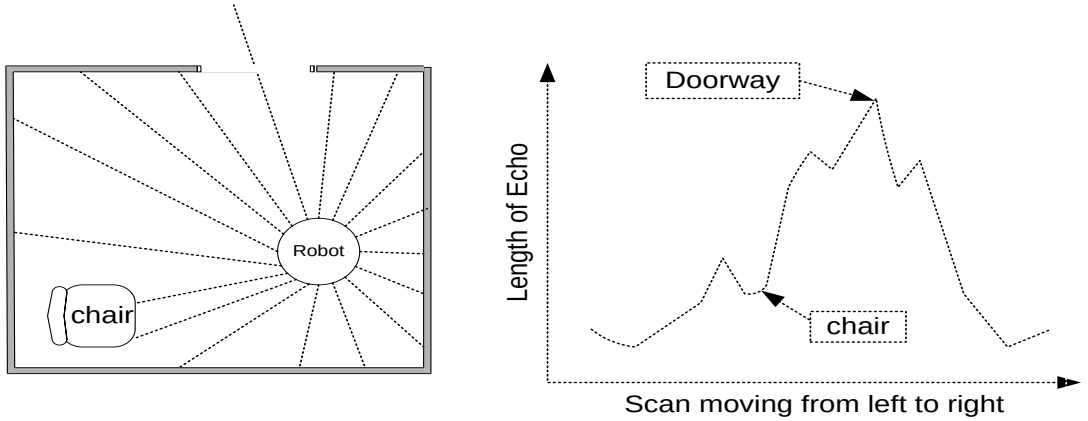


Sensor Specification

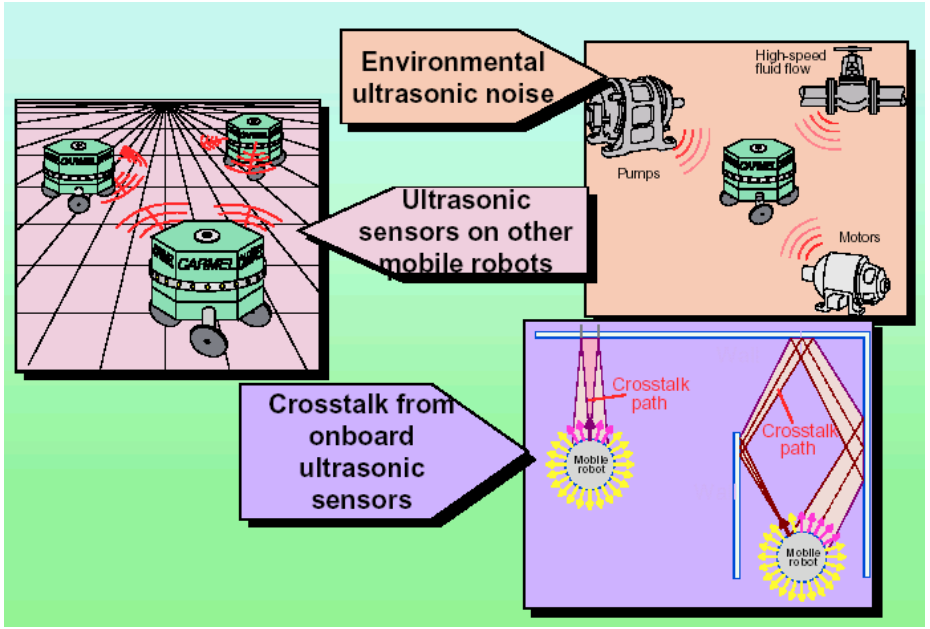
Sensor Model, angle = 15 degrees

Sonar

- Usage:
  Mapping of space

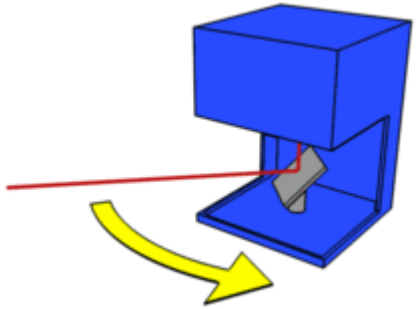


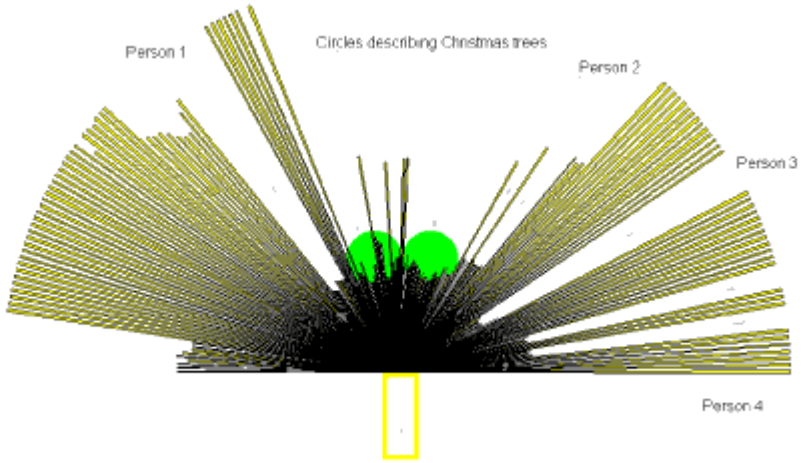
- Problem:
  noise,
  interference



Laser range sensors

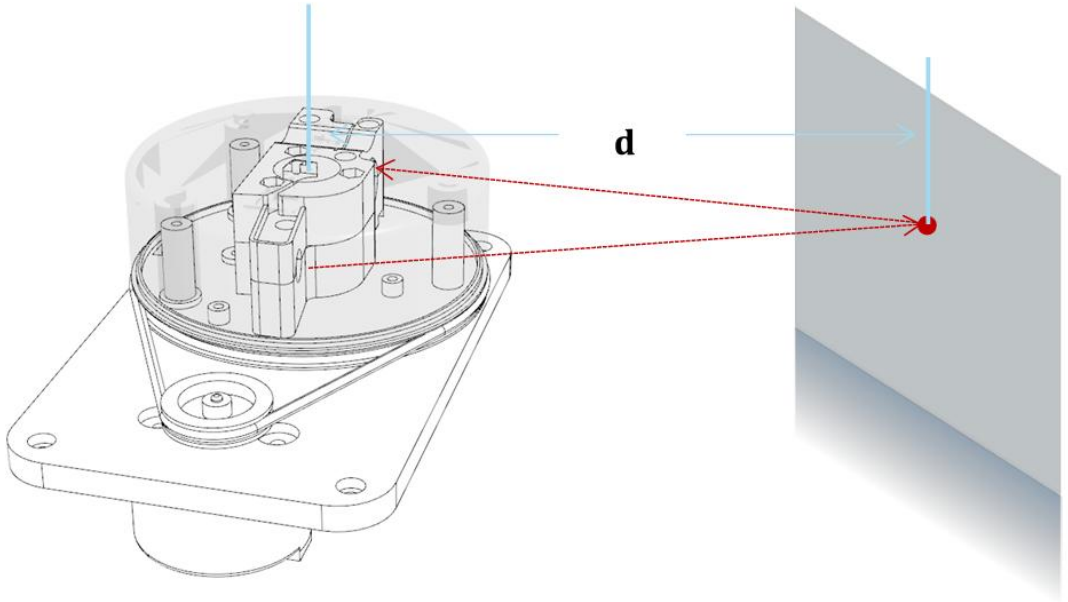
- LIDAR (**Li**ght **D**etection **A**nd **R**anging)
- Emits laser pulses
- Rotating mirror – different angles (up to 180 degrees)
- Vertical movement – the entire hemisphere
- Better angular accuracy (0.25 degrees)
- Faster
- Different ranges, indoor, outdoor
- Robust

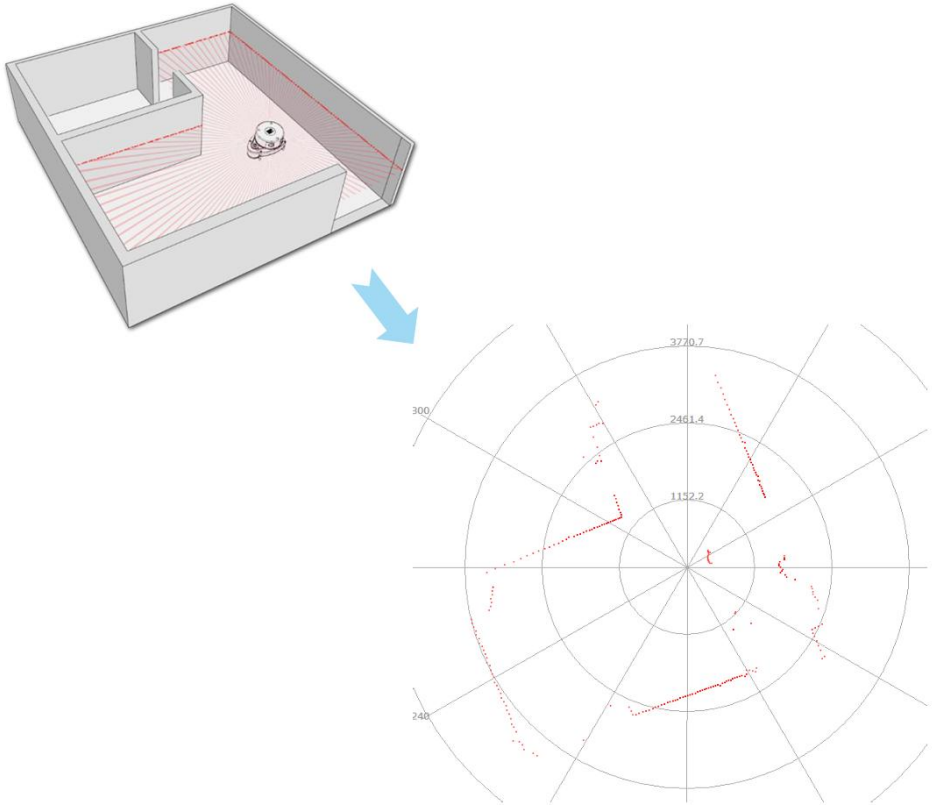




Triangulation based LIDAR

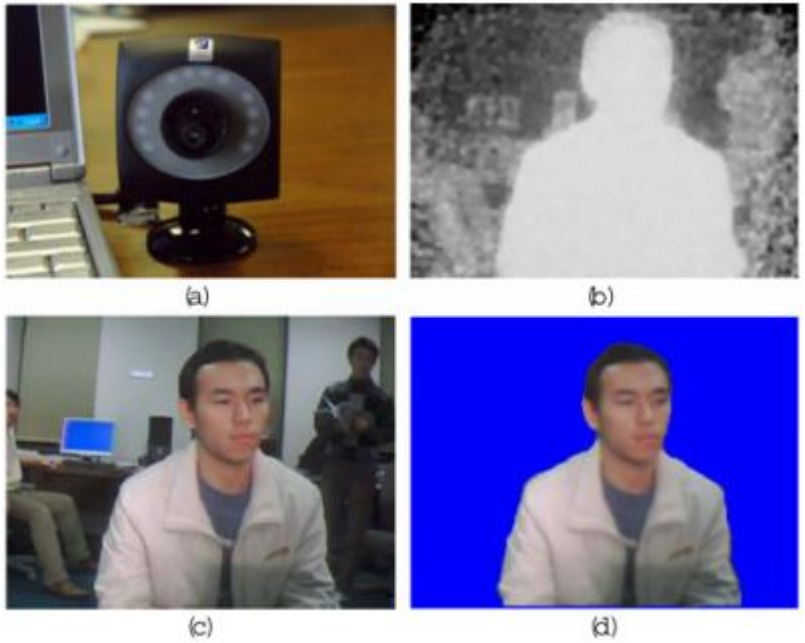
- Low-cost LIDARs
- Based on triangulation, and not ToF





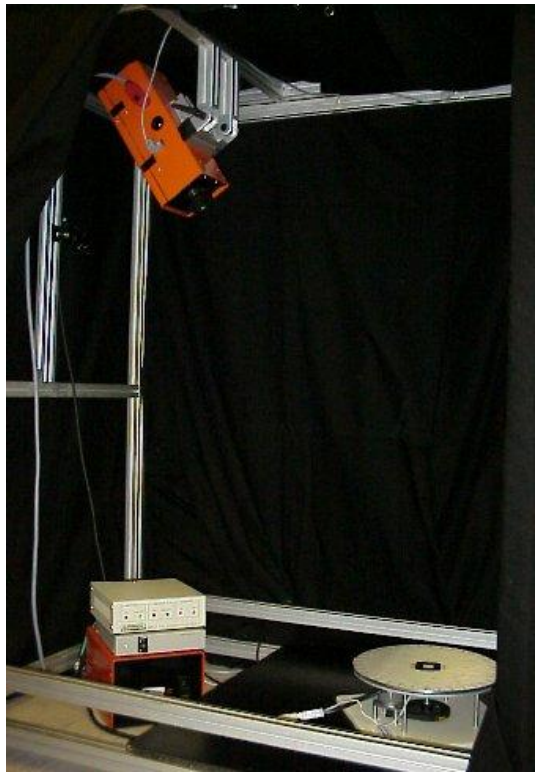
TOF cameras

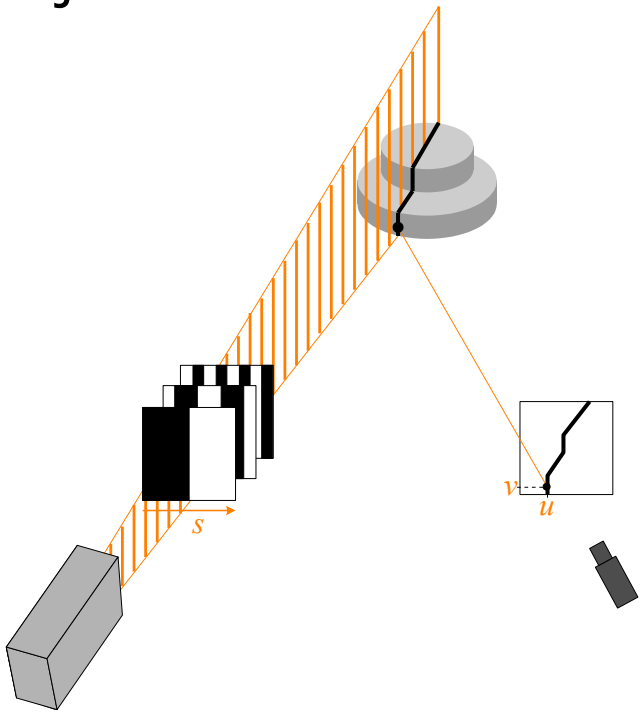
- Time-of-flight cameras
- Time of pulse travel

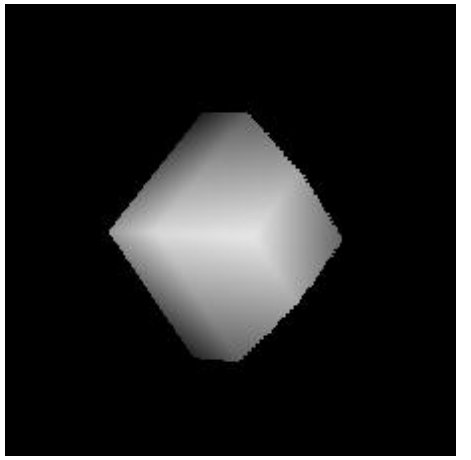


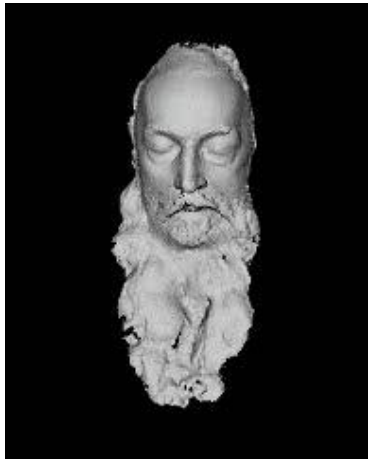
Coded light range sensor

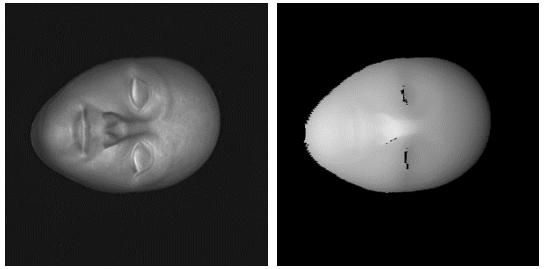
- Camera and stripe projector



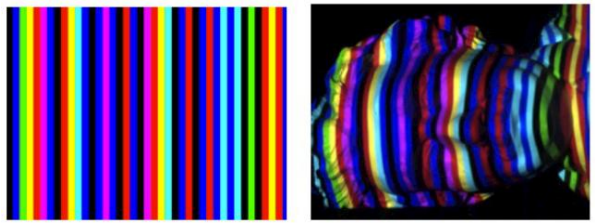




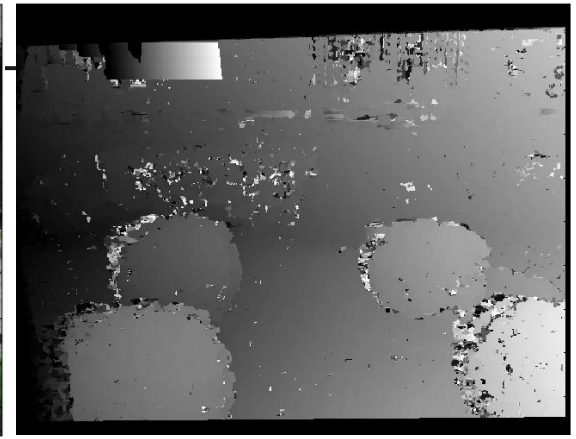


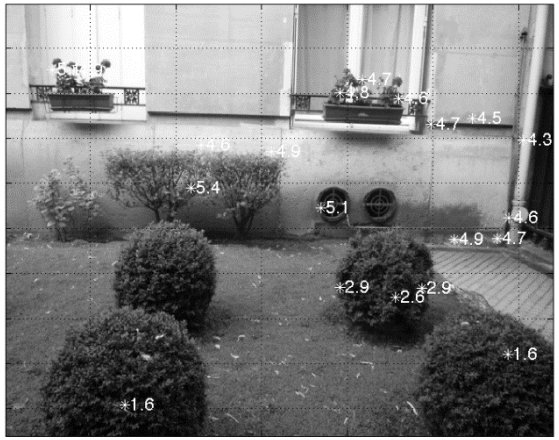


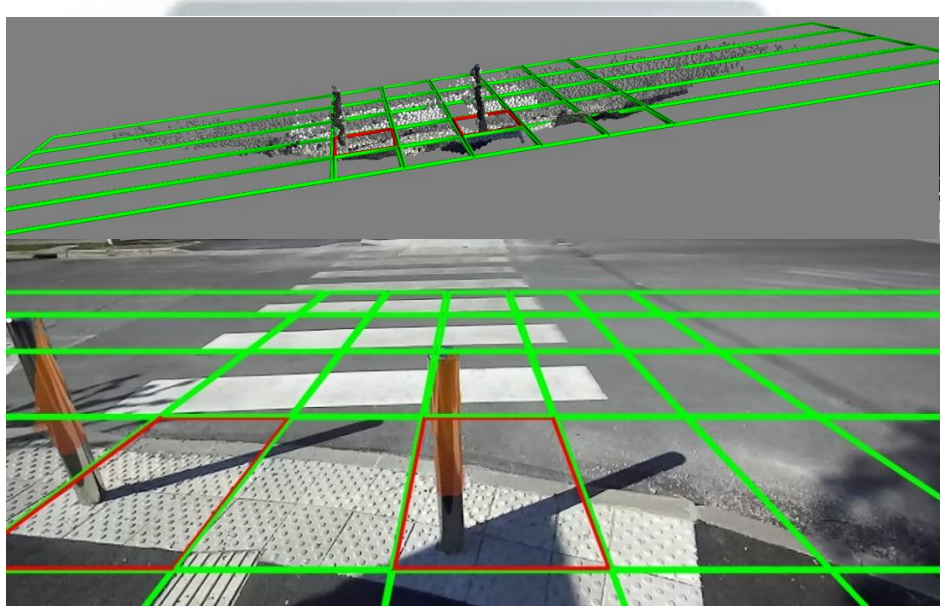
Color coding:



Stereo cameras

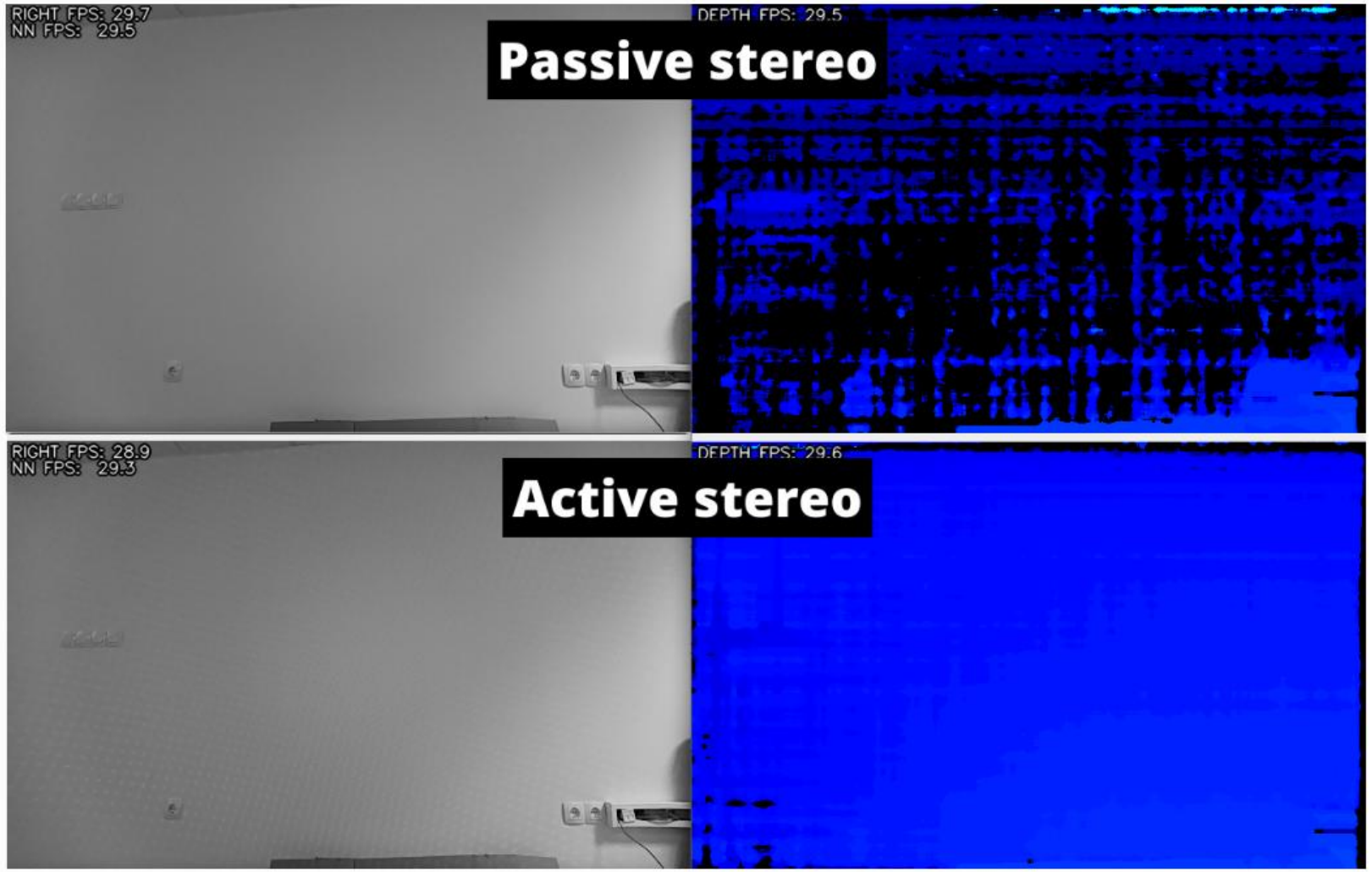




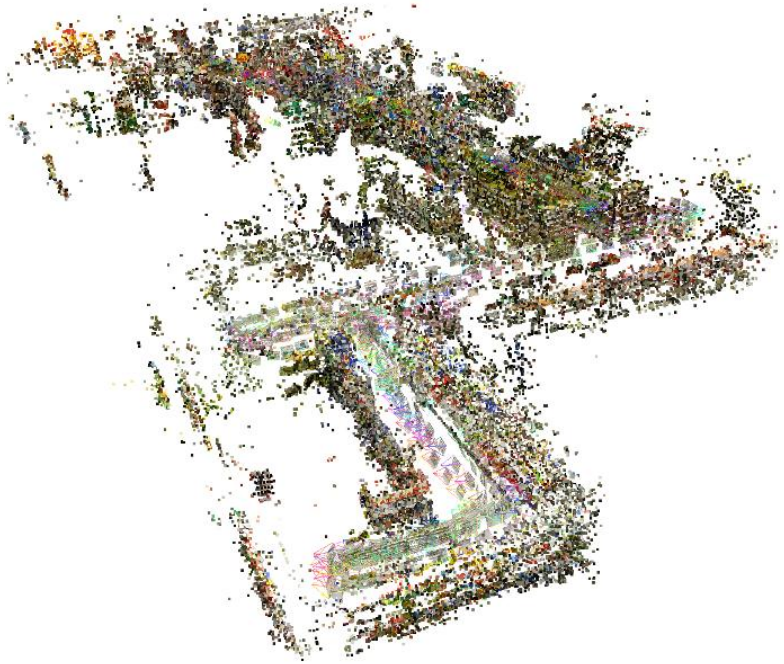


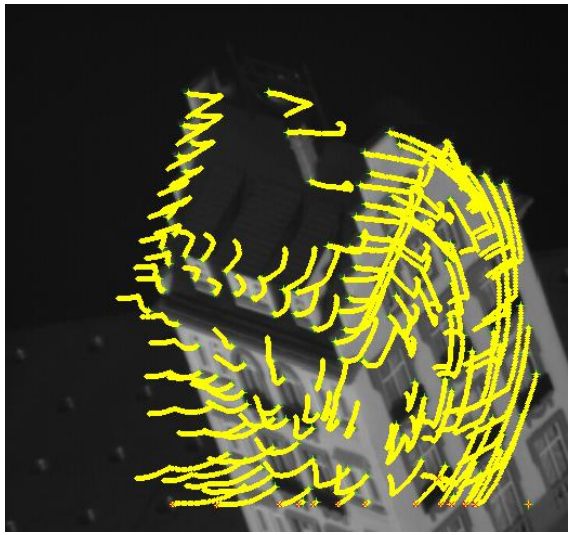
Active stereo vision

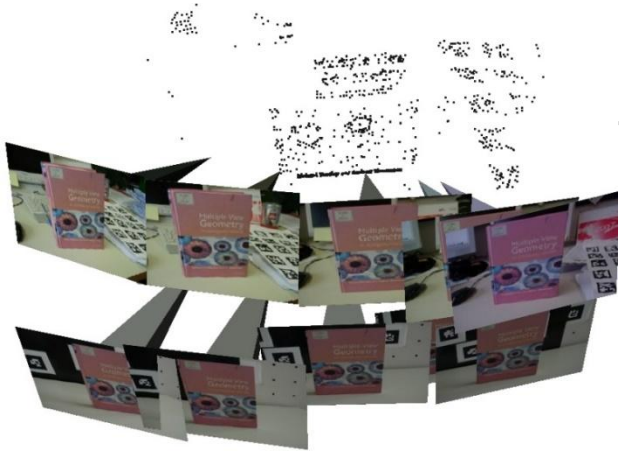
- Actively project (an IR) pattern to increase the texture on the surfaces

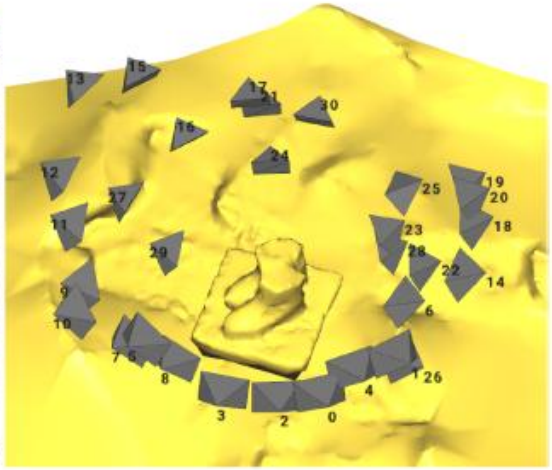


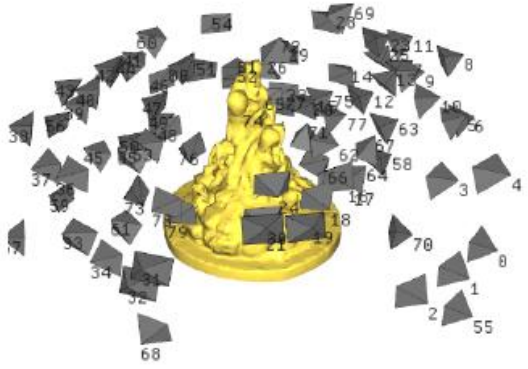
Structure from motion

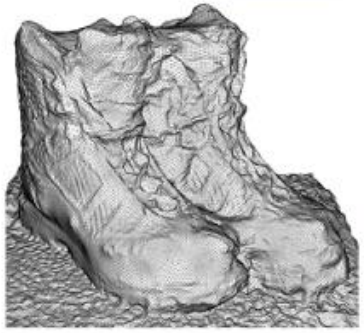










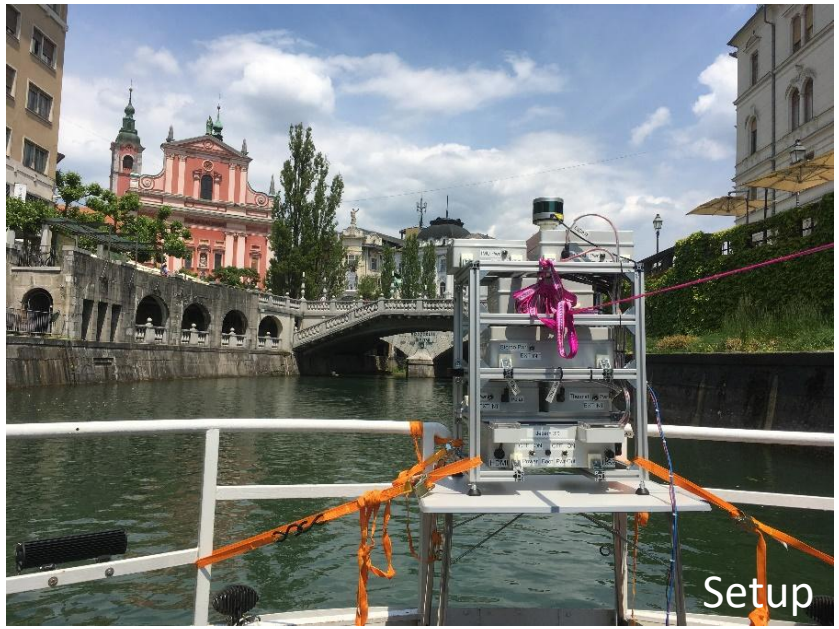


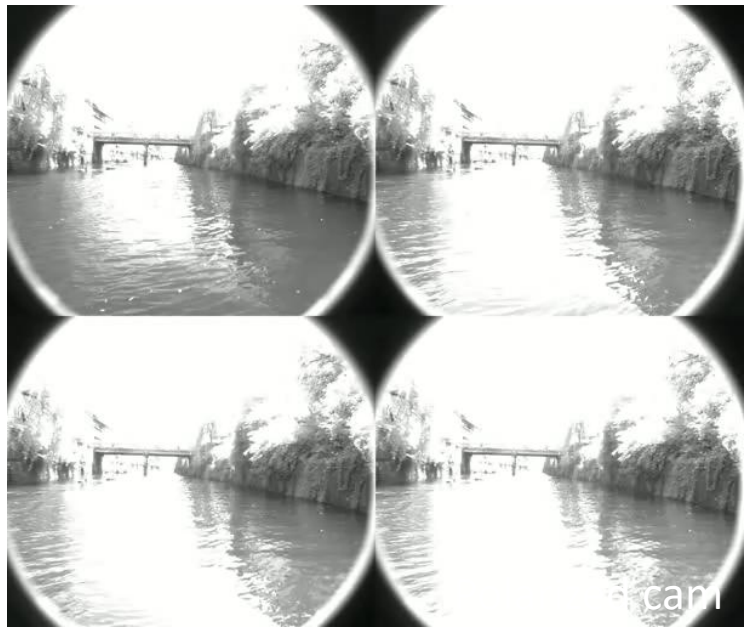
Other sensors

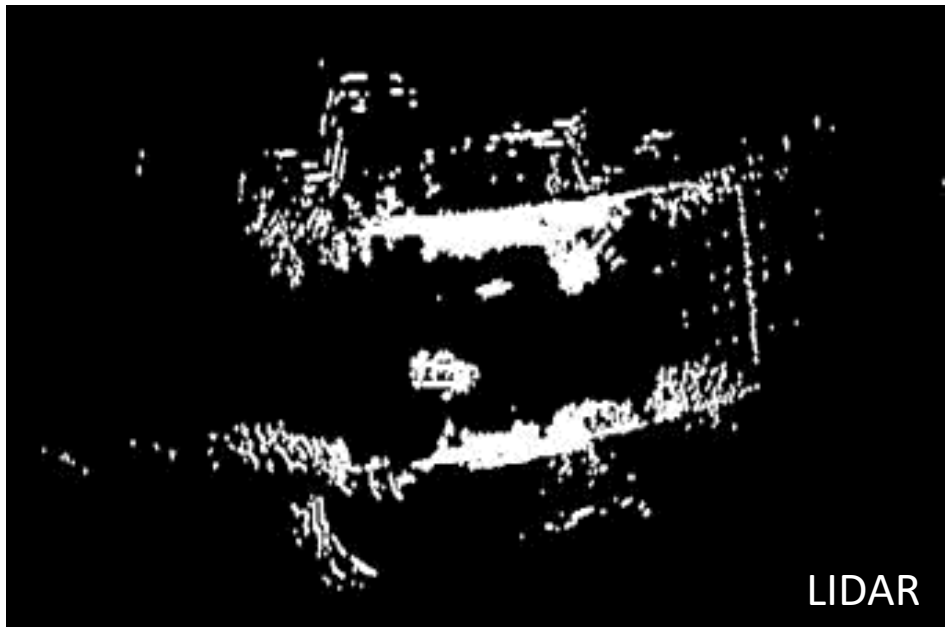
- Exteroceptive sensors
  - Wind speed
  - Temperature
  - Humidity

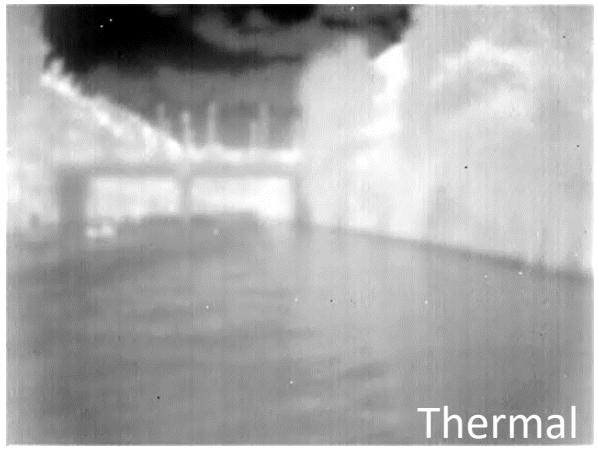
- Proprioceptive sensors
  - Baterry level
  - Temperature of CPU, motors, sensors, etc.

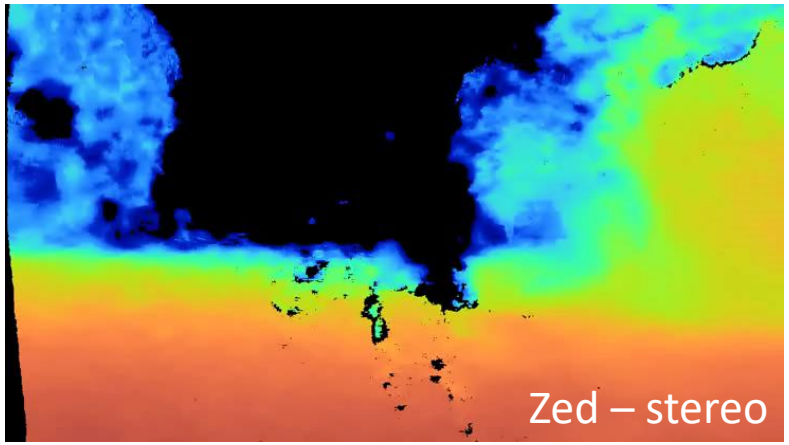
Multimodal perception

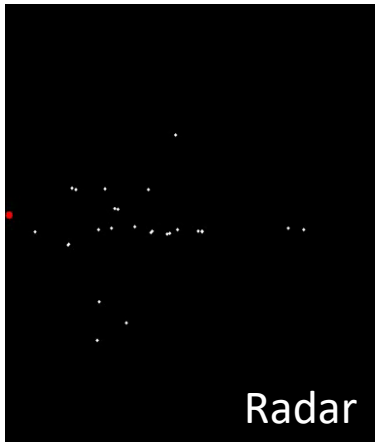












UL FE, FRI, Janez Perš, Matej Kristan

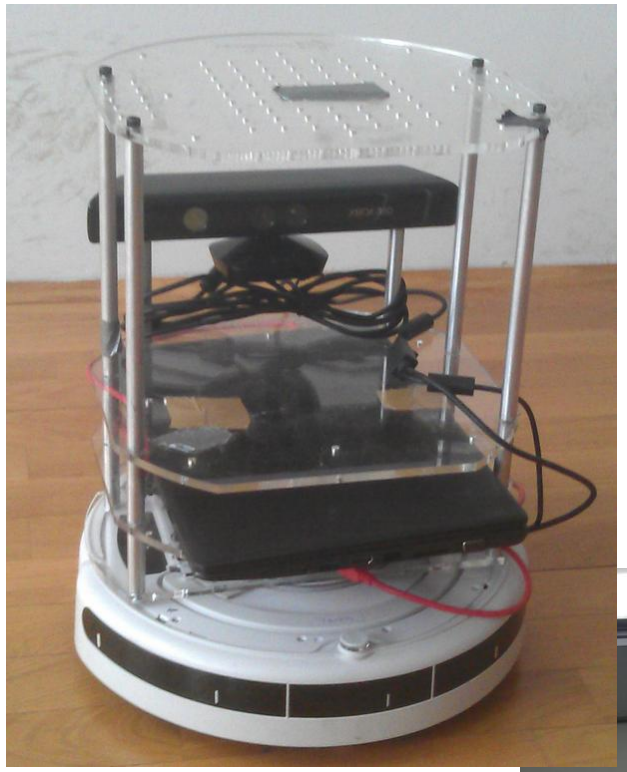
Sensor fusion

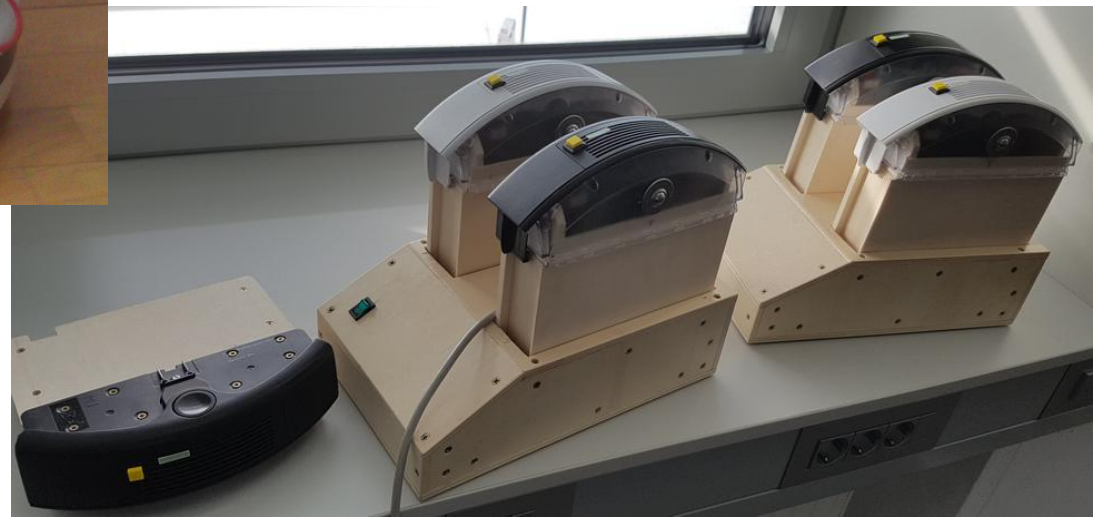
- One sensor often does not suffice
  - Noise
  - Limited accuracy
  - Non-reliabilty
  - Limited sensing range

=>Fuse the results of several sensors

- Sensor fusion: fusion on the level of sensors
  - Combine signals in one data structure on a low level
- Sensor integration: Fusion on the level of representations
  - Process data from every sensor independently and merge the obtained information on a higher level
- Fusion of data from multiple sources:
  - Measurement from different sensors
  - Measurement from different times
  - Measurement from different locations

TurtleBot++



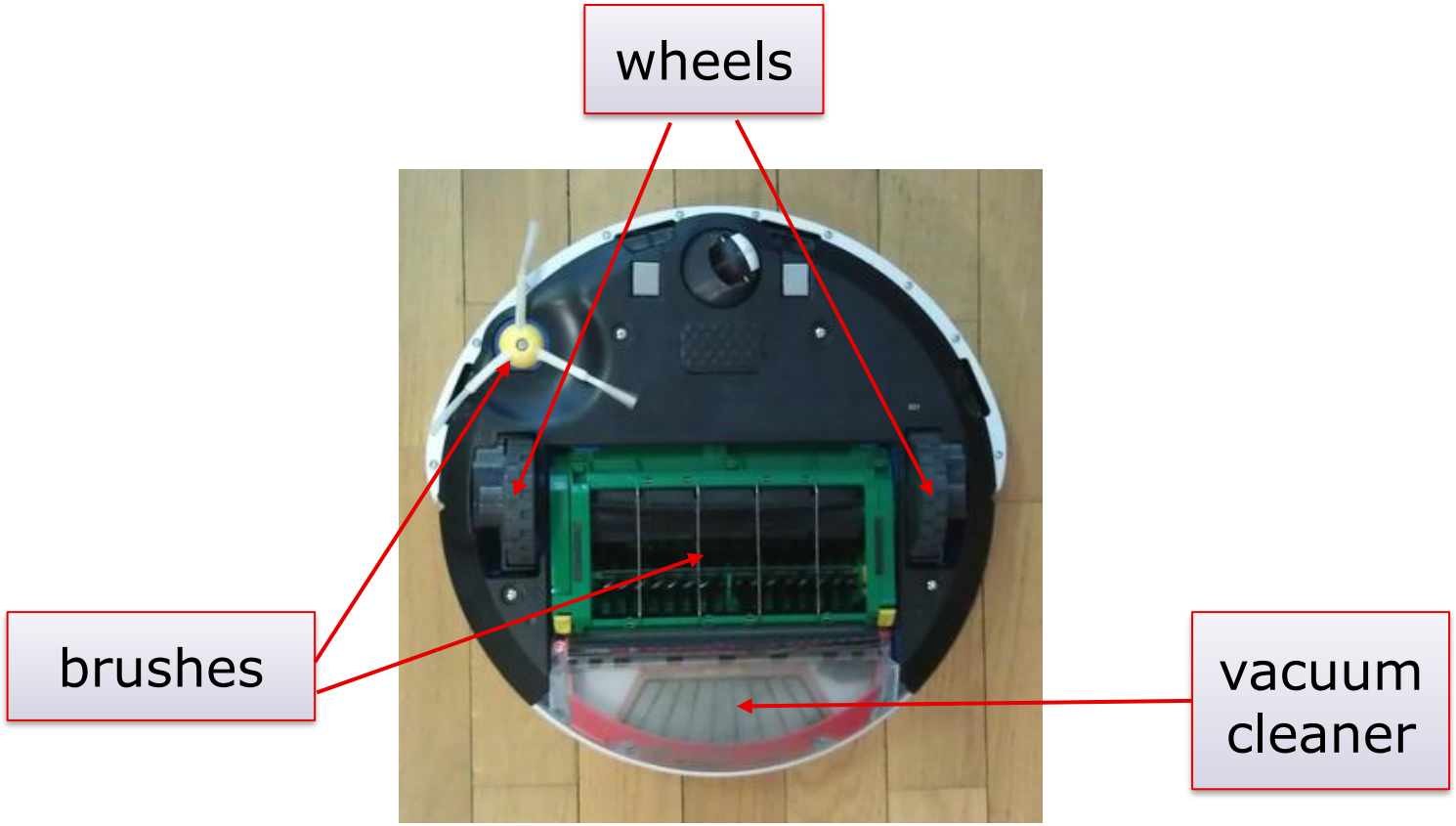


iRobot Roomba

- Actuators and sensors

Motors

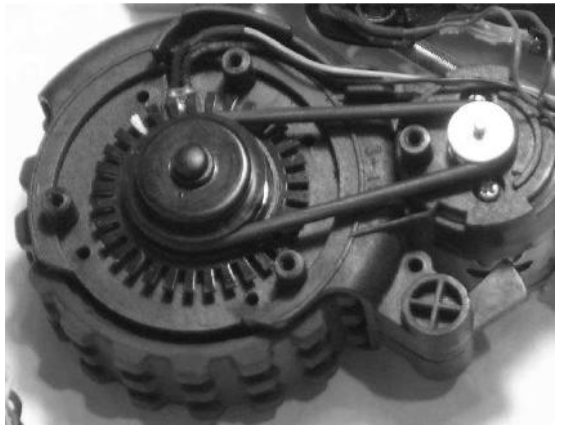
- Changeable speed of the wheels
  - pulse-width modulation (PWM)

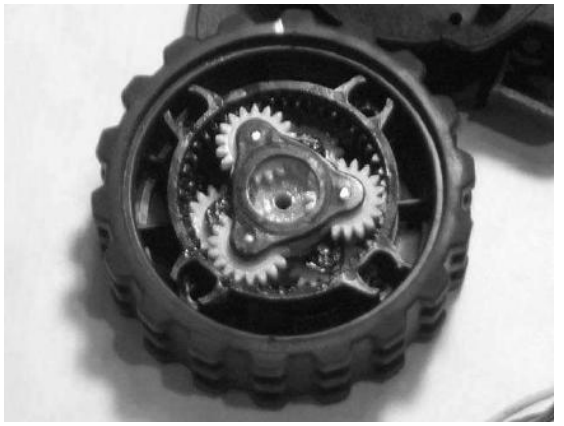


- On/off motors for brushes and vacuum cleaner

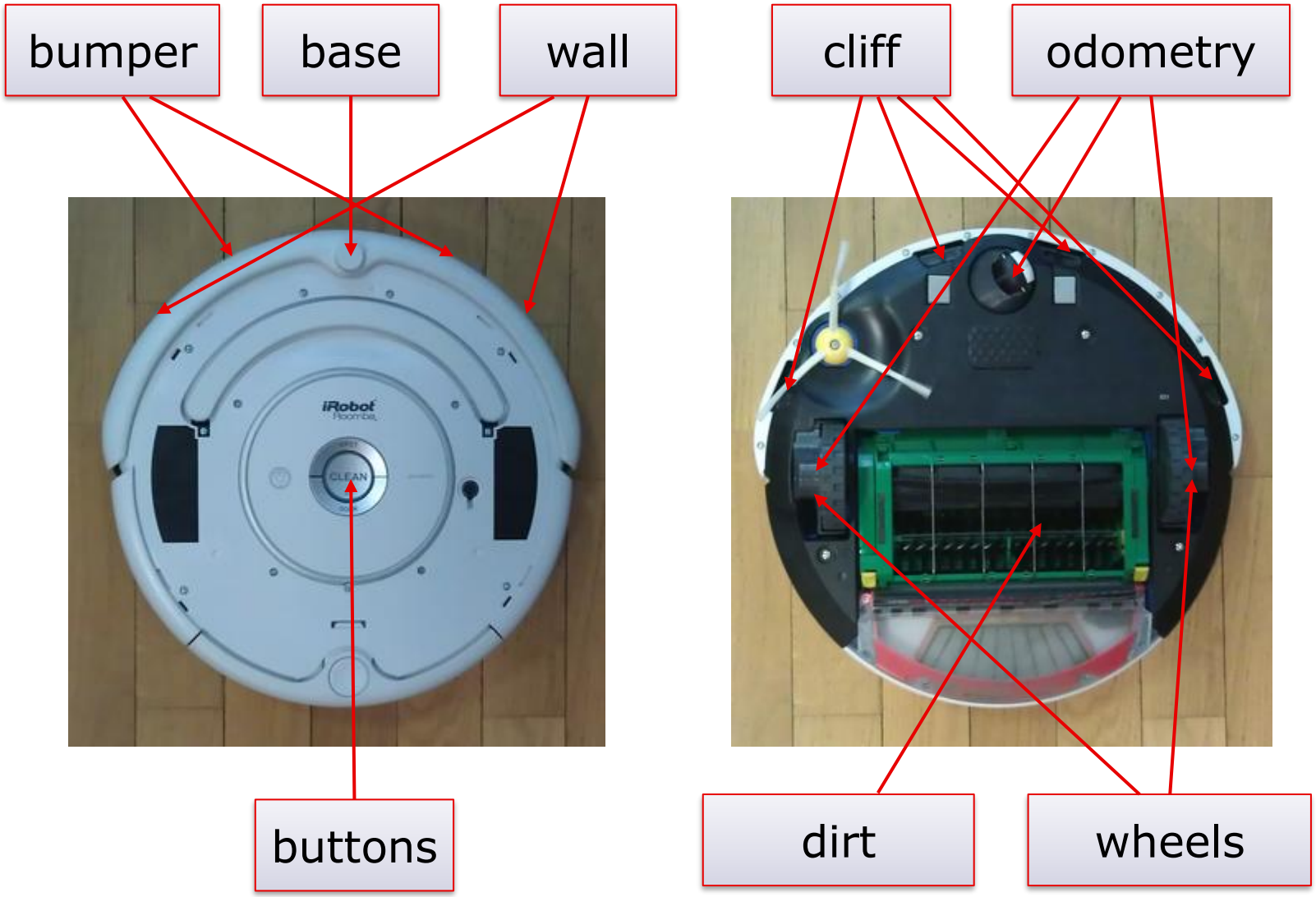
Wheels

- Differential control system
  - Two independently controlled wheels
- Electric motor
  - high speed
- 25:1 reduction
  - large torque



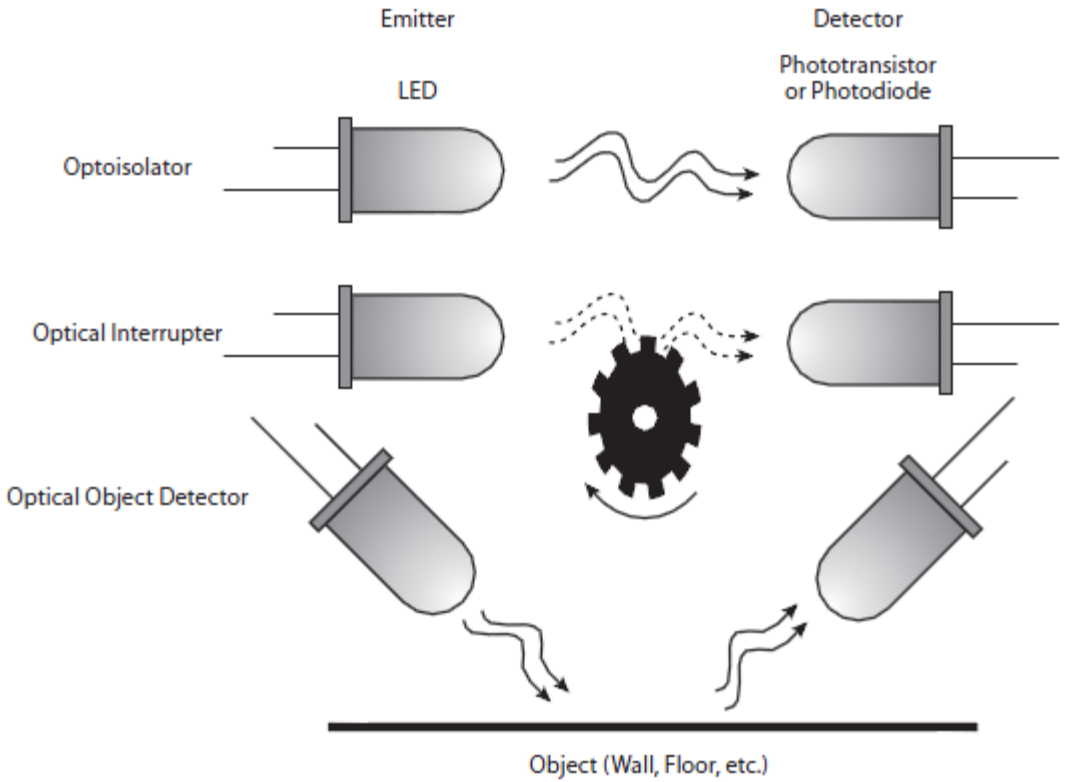


Sensors



IR sensors

- IR sensors



base

bumper

odometry

wall

cliff

- Micro switches:

buttons

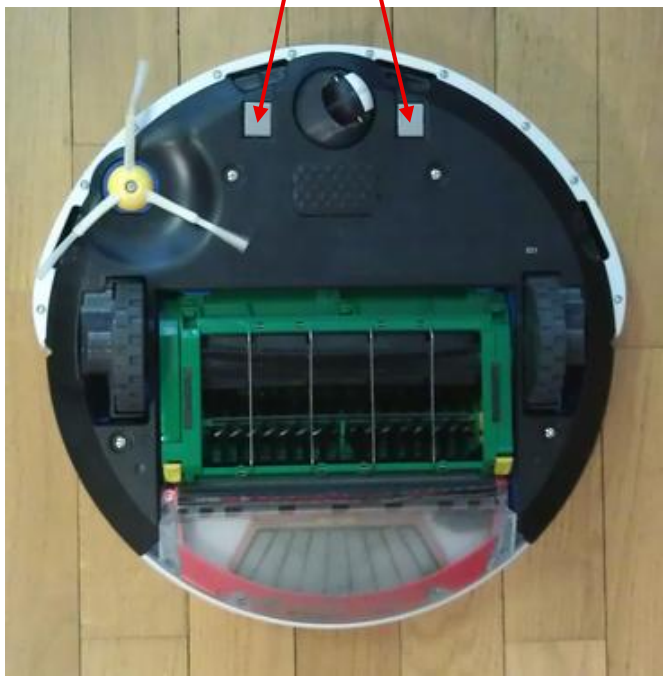
wheels

- Capacitive sensor:

dirt

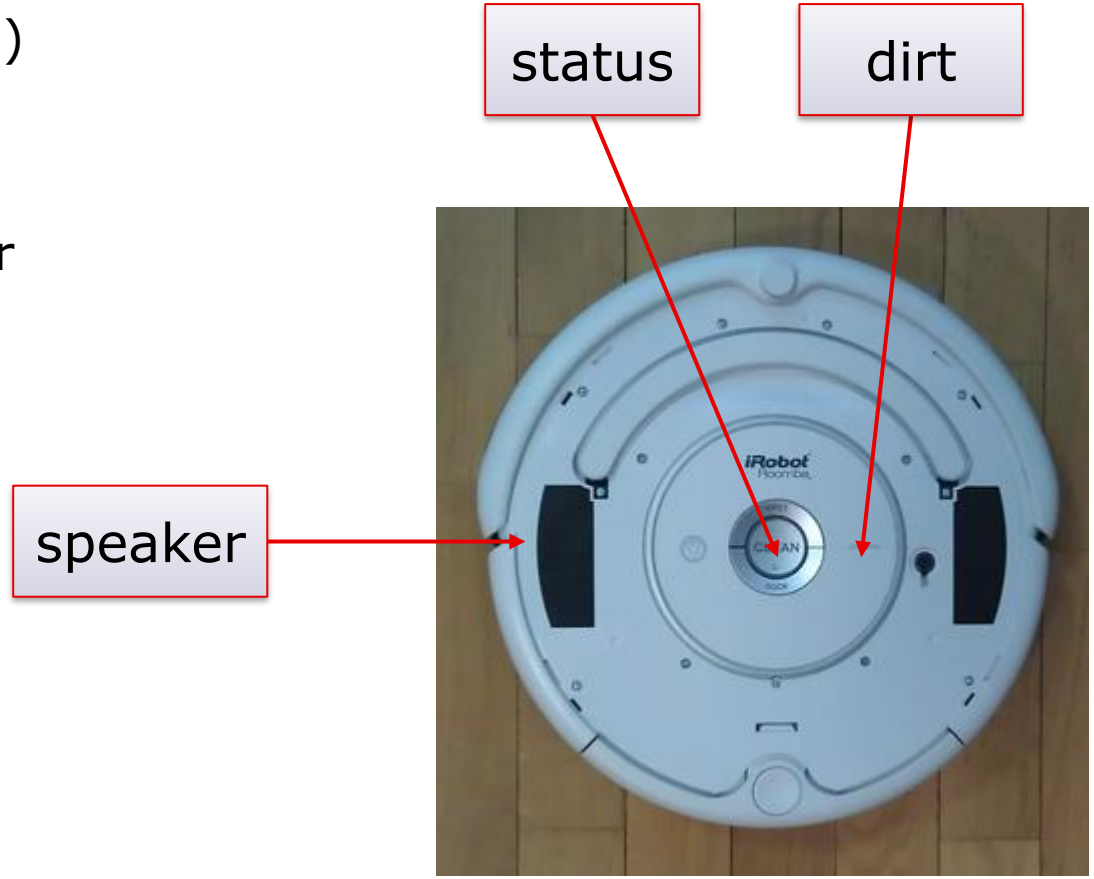
Power supply

- Measuring power supply
  - capacitance of the accumulator [mAh]
  - voltage [V]
  - current [A]
  - temperature



Indicators

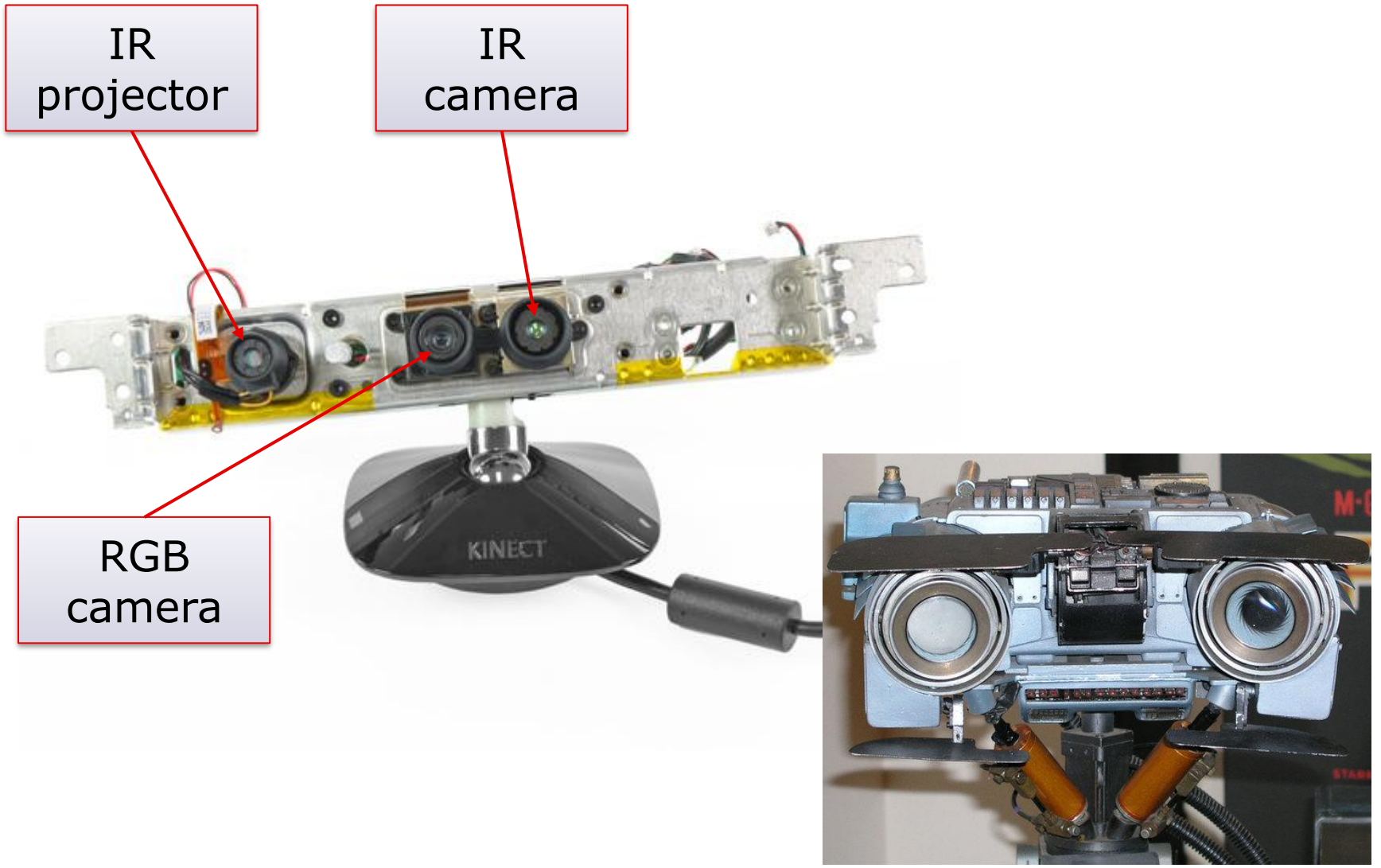
- Led lights
  - Status (green, red)
  - Dirt detection (blue)
- Speaker
  - piezoelectric beeper



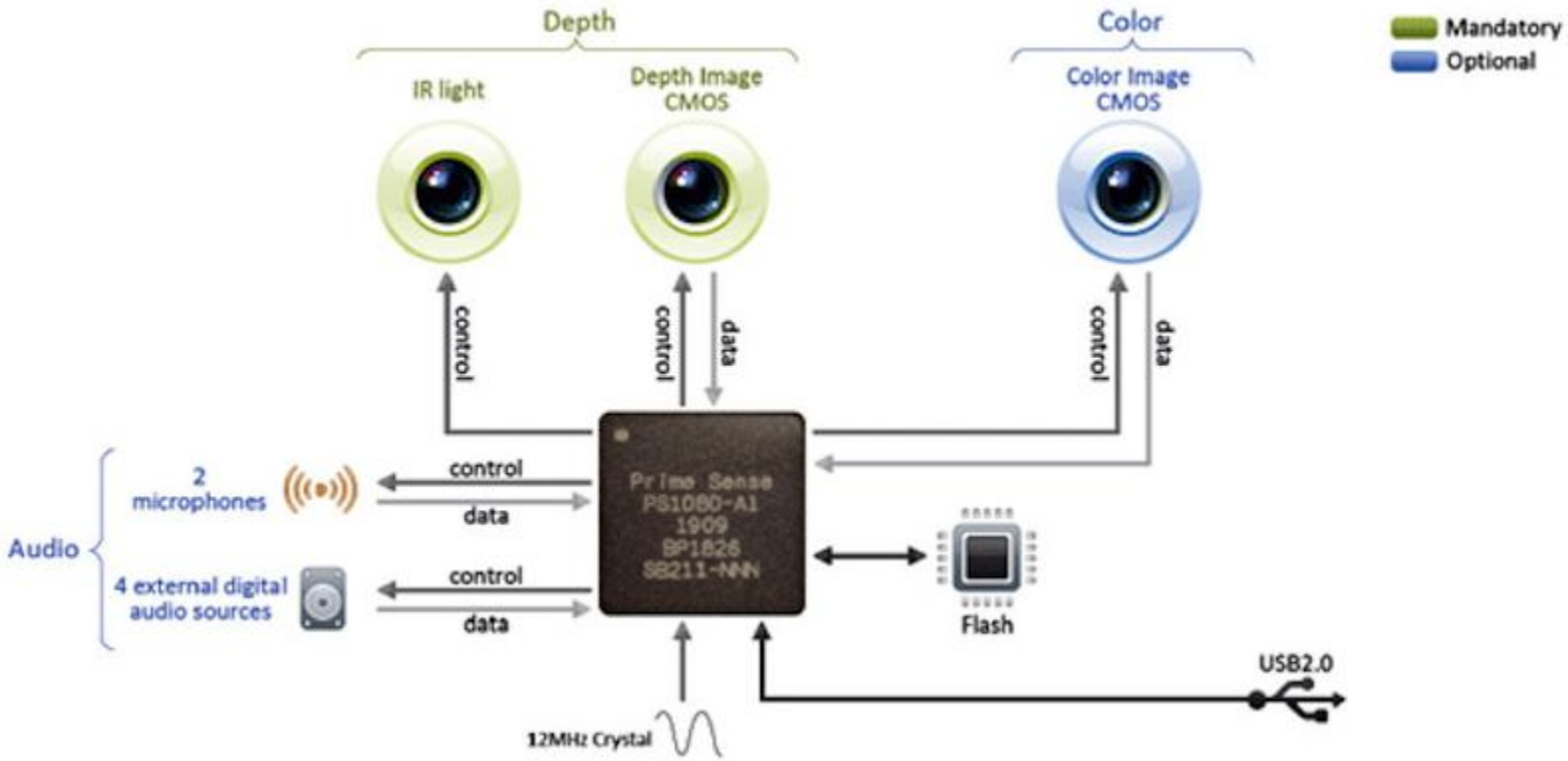
RGBD sensor Kinect

- PrimeSense sensor

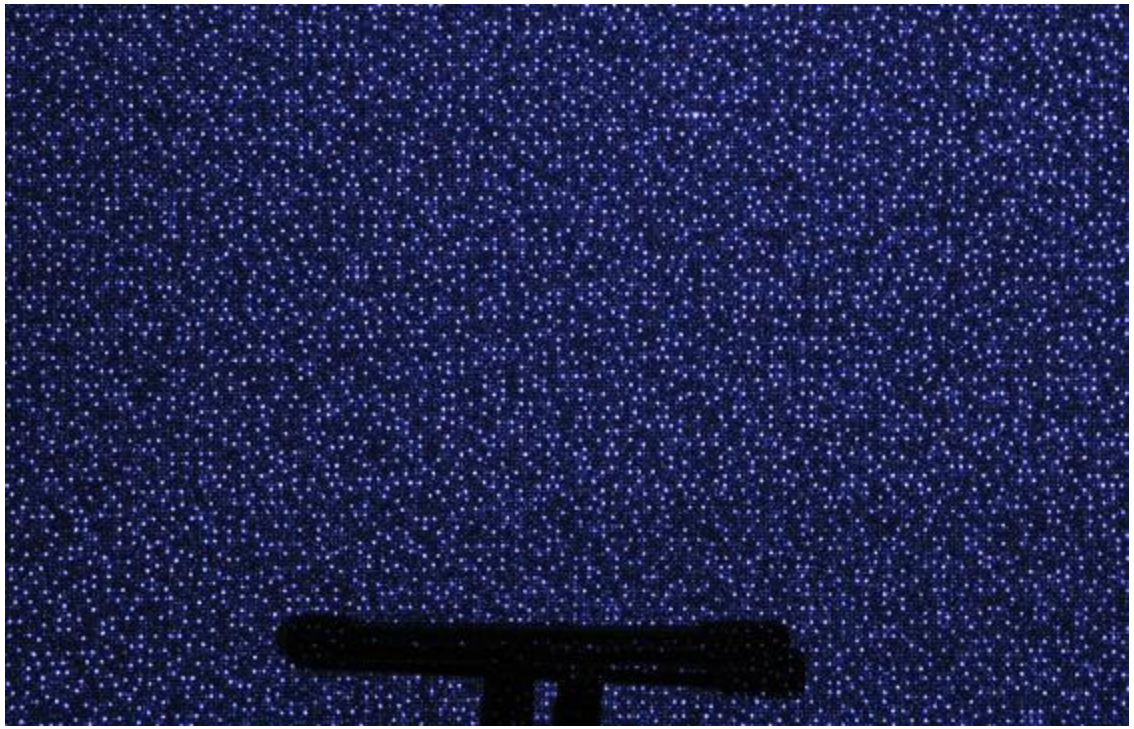
Components



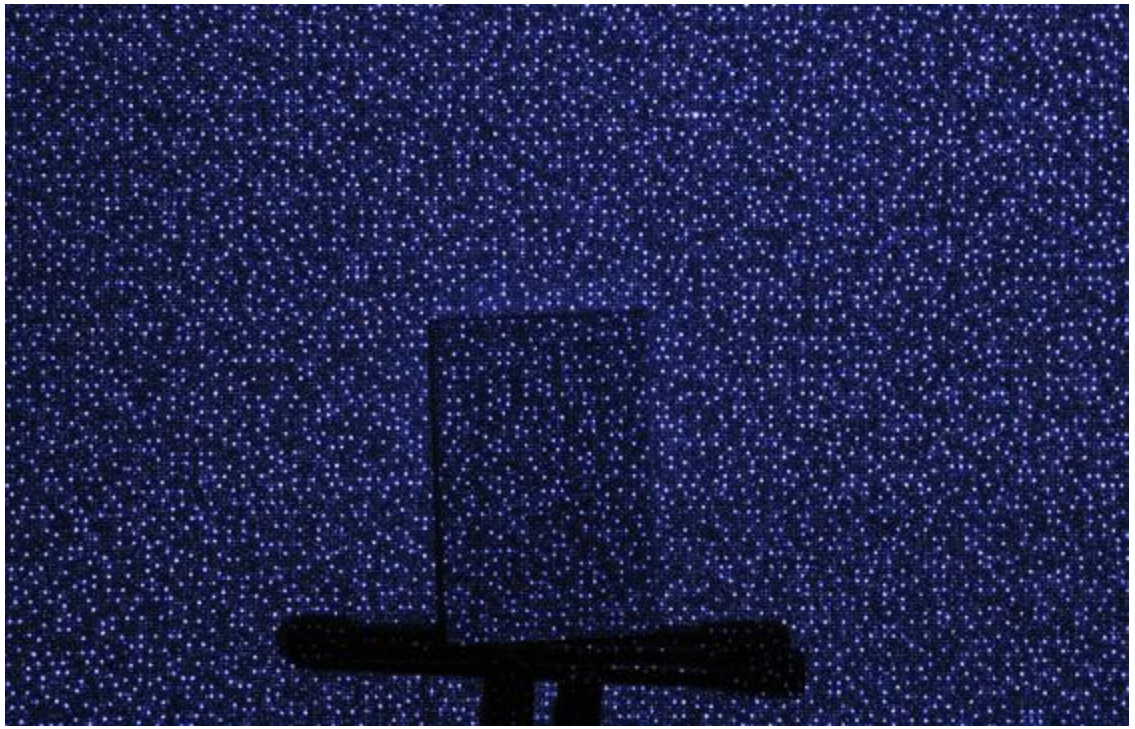
Scheme


Depth
IR light
Depth Image CMOS
Color
Color Image CMOS
Mandatory
Optional
control
control
data
control
data
2 microphones
control
data
Audio
4 external digital audio sources
control
data
Flash
USB2.0
12MHz Crystal

Projected pattern



Projected pattern



Patent

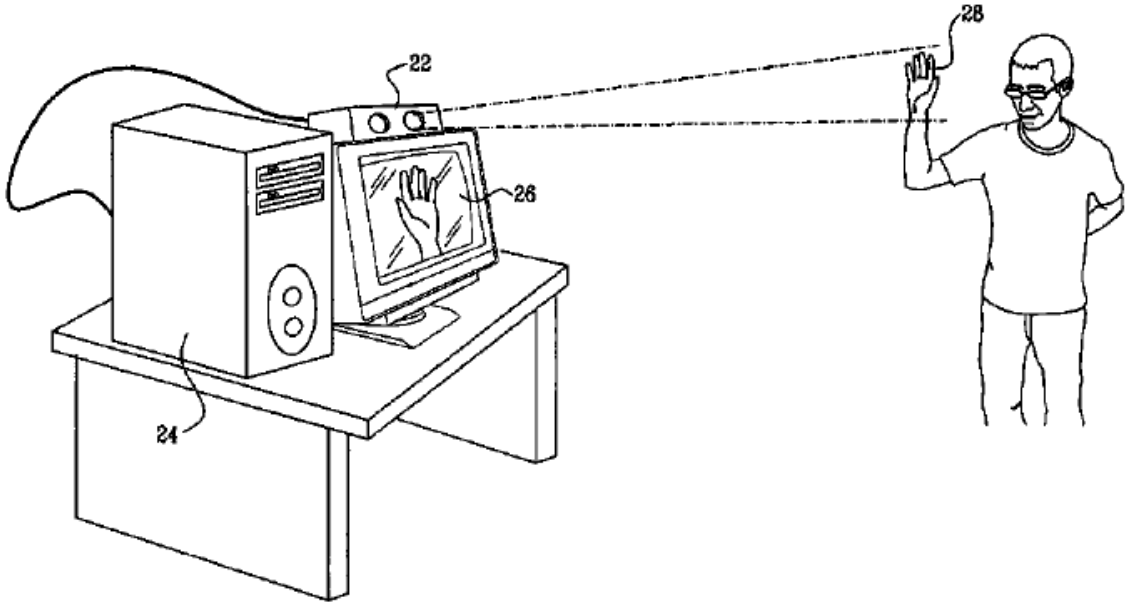
Patent No.: US 7,433,024 B2

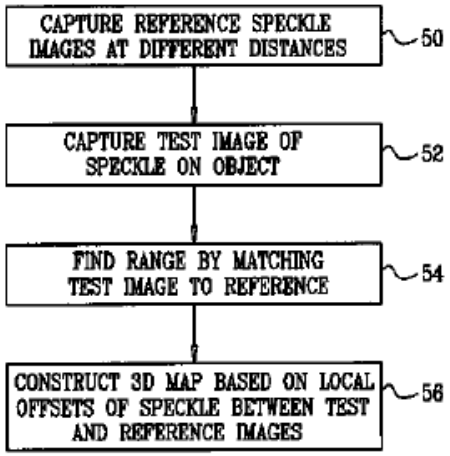
RANGE MAPPING USING SPECKLE DECORRELATION

(57) **ABSTRACT**

A method for mapping includes projecting a primary speckle pattern from an illumination assembly into a target region. A plurality of reference images of the primary speckle pattern are captured at different, respective distances from the illumination assembly in the target region. A test image of the primary speckle pattern that is projected onto a surface of an object in the target region is captured and compared to the reference images so as to identify a reference image in which the primary speckle pattern most closely matches the primary speckle pattern in the test image. The location of the object is estimated based on a distance of the identified reference image from the illumination assembly.

Patent


22
28
26
24


CAPTURE REFERENCE SPECKLE IMAGES AT DIFFERENT DISTANCES
50
CAPTURE TEST IMAGE OF SPECKLE ON OBJECT
52
FIND RANGE BY MATCHING TEST IMAGE TO REFERENCE
54
CONSTRUCT 3D MAP BASED ON LOCAL OFFSETS OF SPECKLE BETWEEN TEST AND REFERENCE IMAGES
56

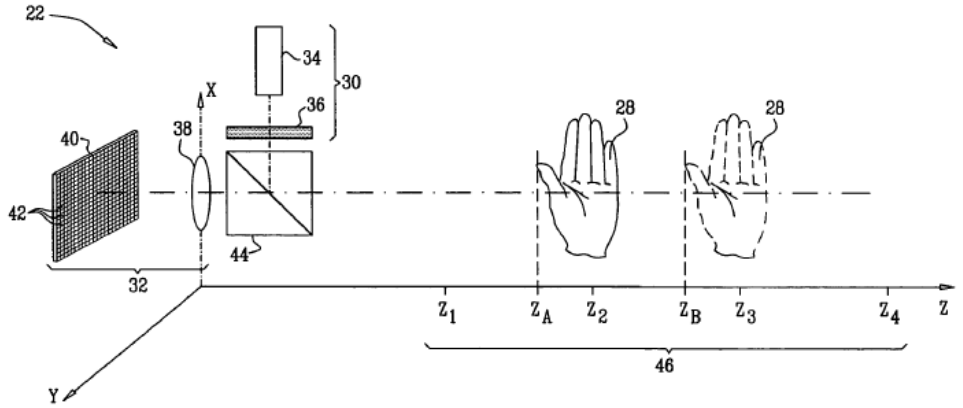
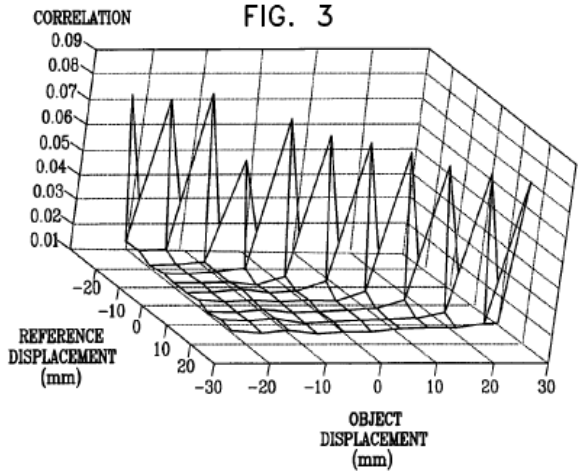
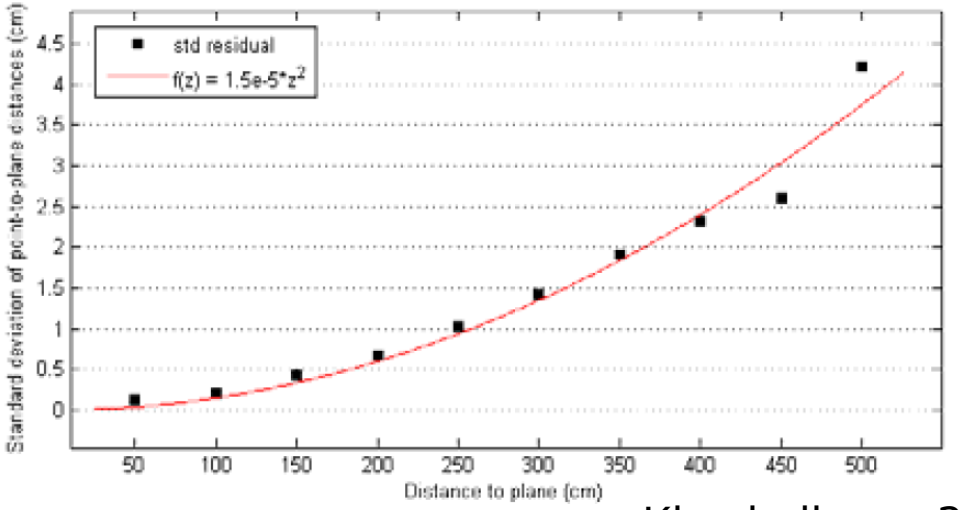

22
34
30
X
36
38
40
42
44
28
28
32
Z_1
Z_A
Z_2
Z_B
Z_3
Z_4
Z
46
Y

FIG. 3


CORRELATION
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
-20
-10
0
10
20
REFERENCE DISPLACEMENT (mm)
-30
-20
-10
0
10
20
30
OBJECT DISPLACEMENT (mm)

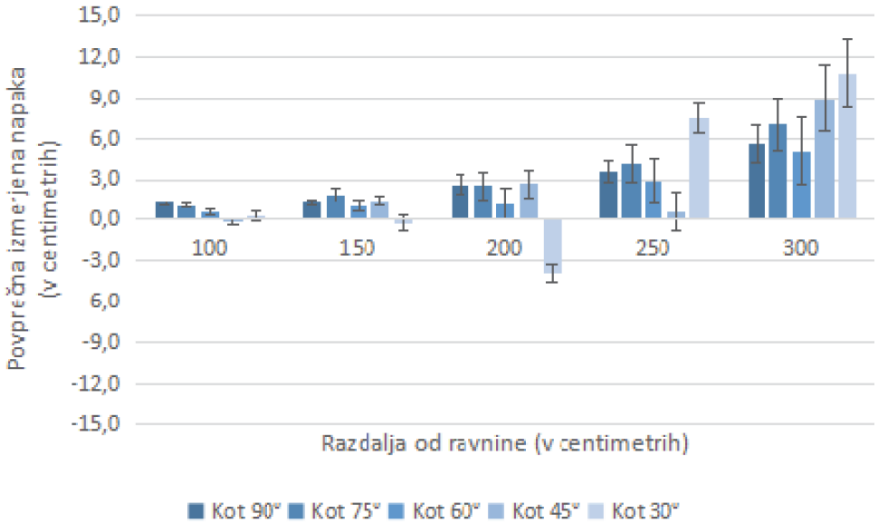
Kinect performance

- Specifications:
  - Horizontal field of view: 57 degrees
  - Vertical field of view: 43 degrees
  - Physical tilt range: ± 27 degrees
  - Depth sensor range: 1.2m - 3.5m
  - 320x240 16-bit depth @ 30 frames/sec
  - 640x480 32-bit colour@ 30 frames/sec
  - 16-bit audio @ 16 kHz



Khoshelham, 2011

Kotnik, 2018

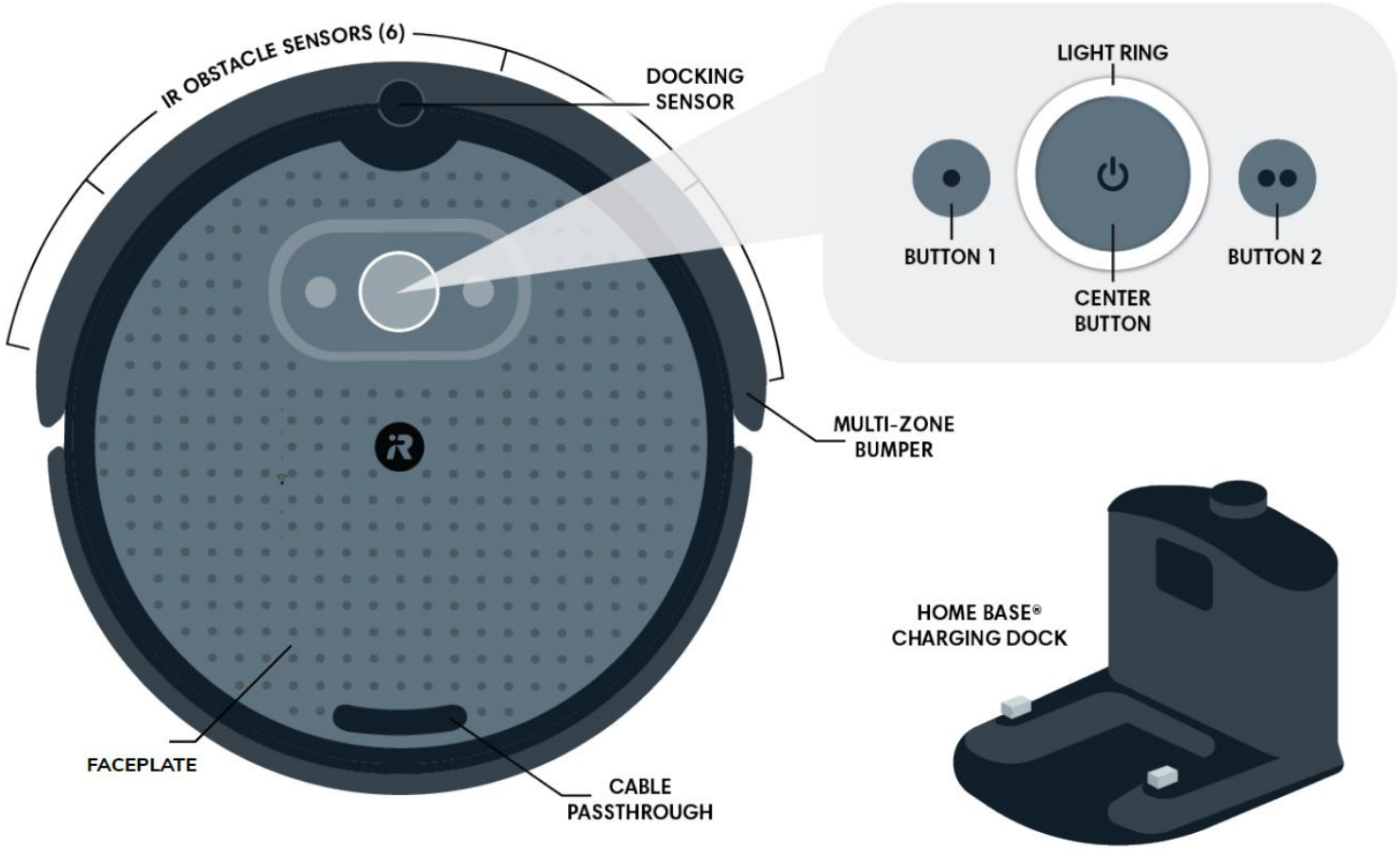


TurtleBot 4

Dimensions	341 x 339 x 351 mm
Weight	3.9 kg
Max. Speed	0.31 m/s
Max. Payload	9 kg - Default 15 kg - Custom Configuration
Operating Time	2.5 - 4.0 hrs (load dependent)
Camera	OAK-D-PRO
LiDAR	RPLIDAR-A1
Accessible Power & USB Ports	Yes
OLED Display	Yes
Mounting Plate	Yes
Software	ROS 2
Computer	Raspberry Pi 4B (4 GB)

TurtleBot 4 Base

- iRobot Create 3



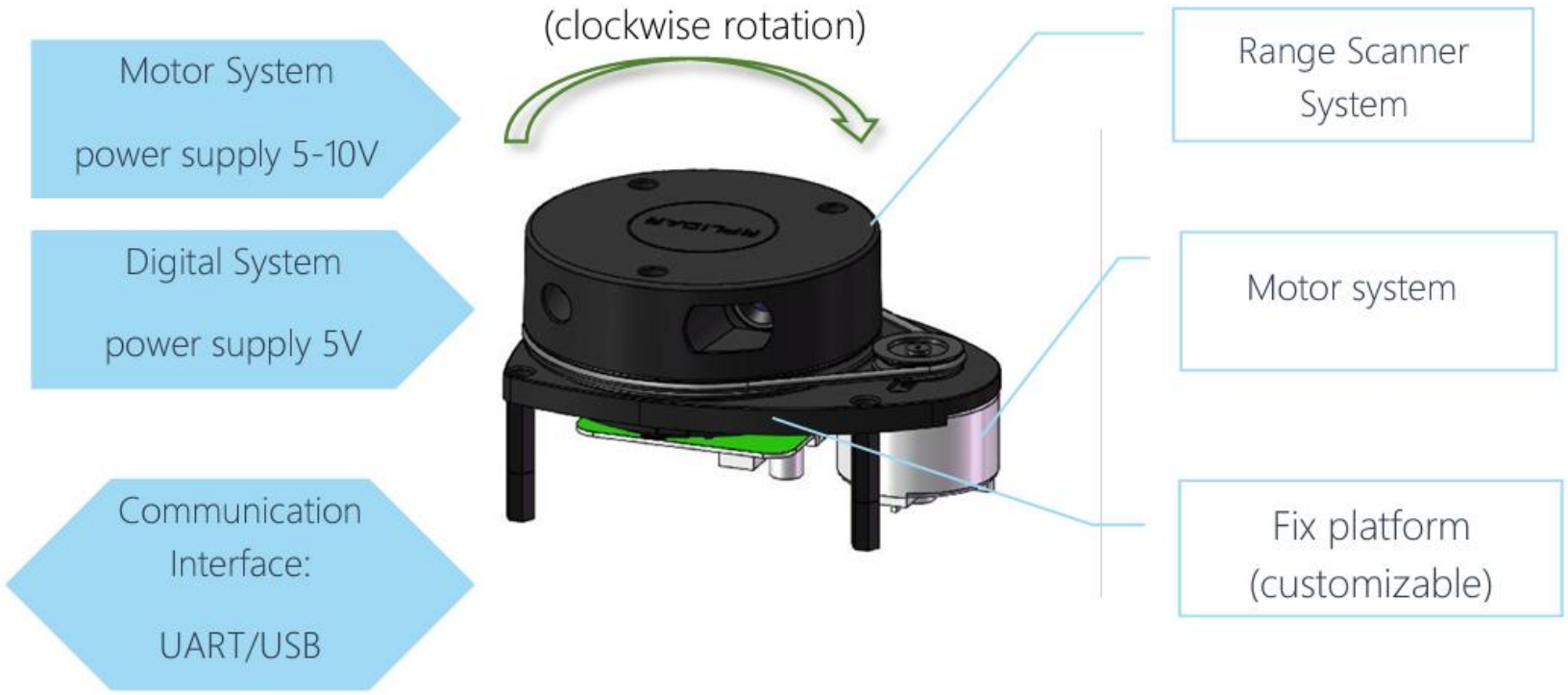
TurtleBot 4 computer

- Raspberry Pi 4B
- 4 USB 3.0 ports

- UI Board
- 128x64 user display

TurtleBot LIDAR

- RPLIDA A1M8
- 360º Laser Range Scanner
- 12m range
- Triangulation-based LIDAR



TurtleBot LIDAR

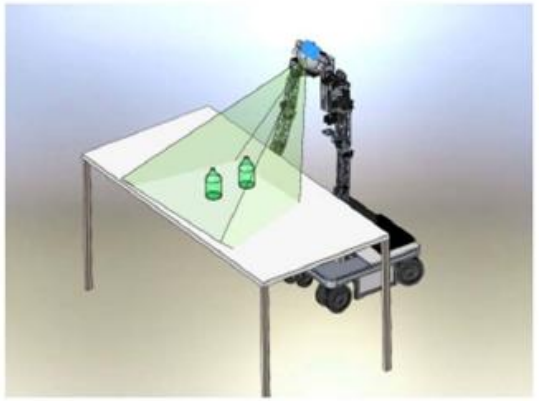
Item	Unit	Min	Typical	Max	Comments
Distance Range	Meter(m)	TBD	0.15-12	TBD	White objects
Angular Range	Degree	n/a	0-360	n/a	
Scan Field Flatness	Degree	-1.5		1.5	
Distance Resolution	mm	n/a	<0.5 <1% of the distance	n/a	<1.5 meters All distance range*
Angular Resolution	Degree	n/a	≤1	n/a	5.5Hz scan rate
Sample Duration	Millisecond(ms)	n/a	0.125	n/a	
Sample Frequency	Hz	n/a	≥8000	8010	
Scan Rate	Hz	1	5.5	10	Typical value is measured when RPLIDAR A1 takes 360 samples per scan

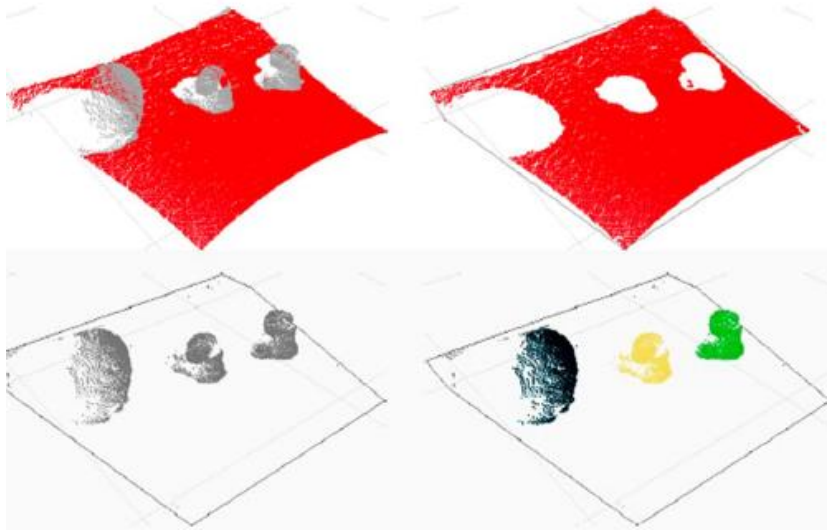
TurtleBot RGBD camera

- Luxonis OAK-D-Pro
- Active stereo vision
  - IR laser dot projection
- IR illumination LED
  - For night vision
- RVC2
  - Robotics Vision Core 2
  - Performanc SoC
  - CV methods…

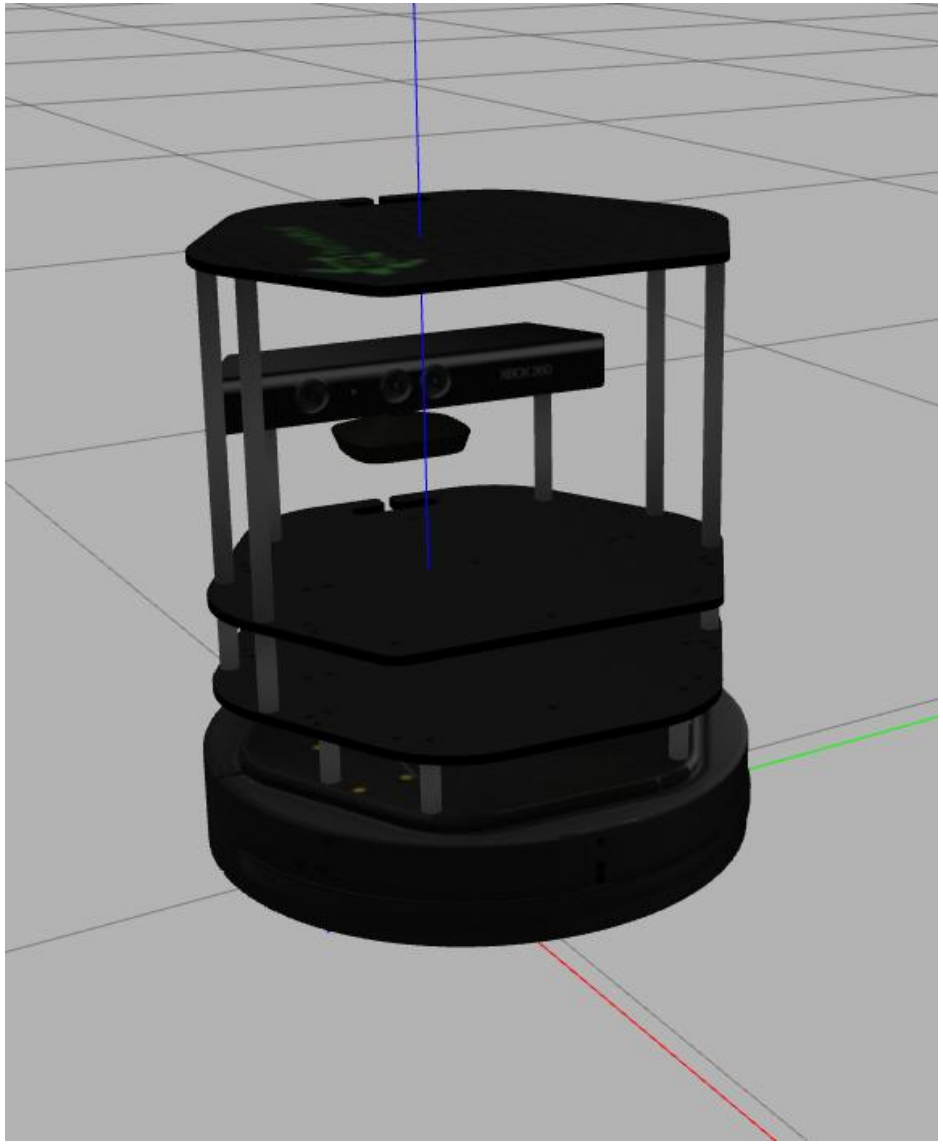
Camera Specs	Color camera	Stereo pair
Sensor	OV9782 (PY074)	OV9282 (PY044)
DFOV / HFOV / VFOV	89° / 80° / 55°	89° / 80° / 55°
Resolution	1MP (1280x800)	1MP (1280x800)
Focus	FF: 19.6cm - ∞	FF: 19.6cm - ∞
Max Framerate	120 FPS	120 FPS
F-number	2.0 ±5%	2.0 ±5%
Lens size	1/4 inch	1/4 inch
Effective Focal Length	2.35mm	2.35mm
Pixel size	3µm x 3µm	3µm x 3µm

RGBD information

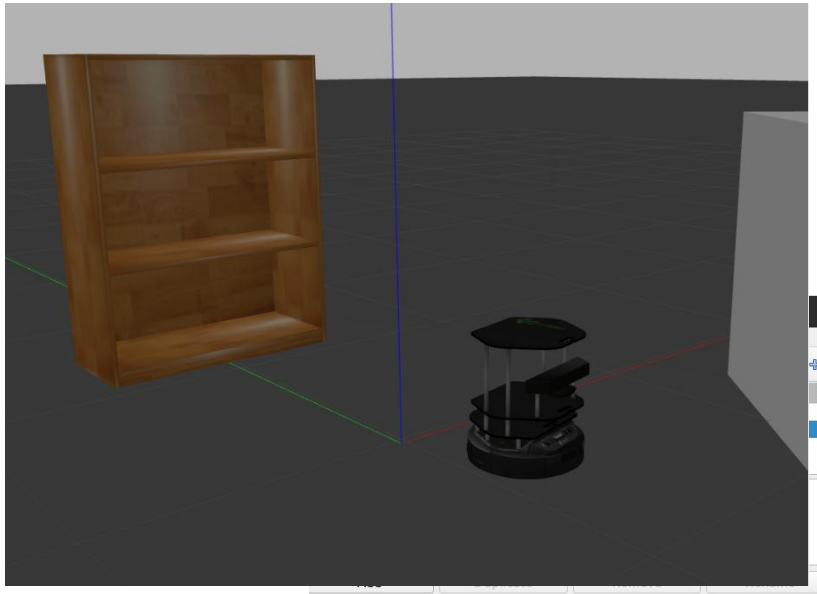


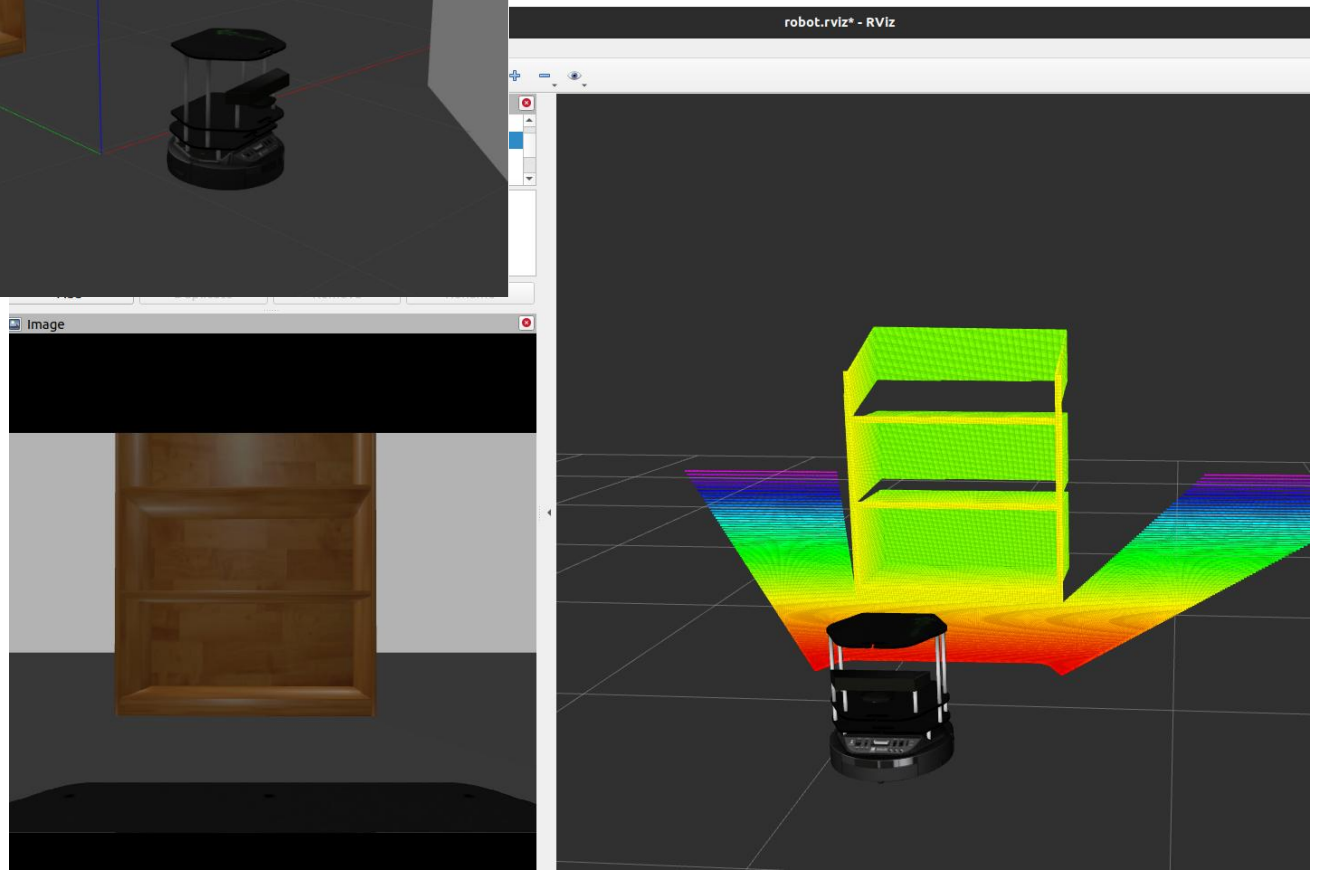


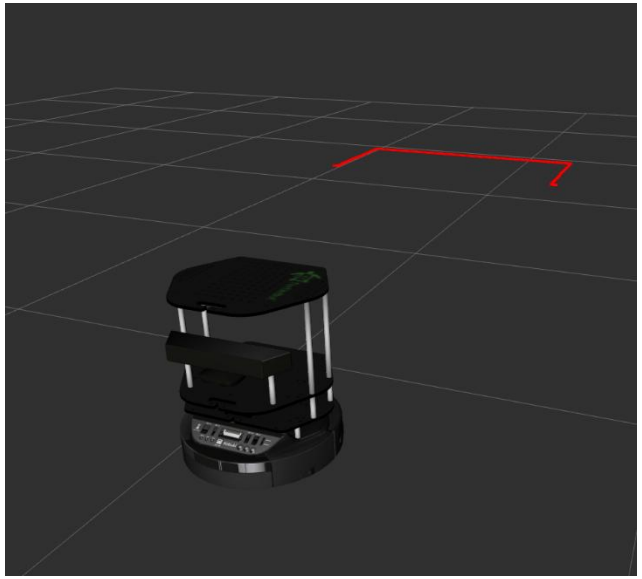
TurtleBot in simulation



Gazebo and RViz







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