University of Illinois at Urbana-Champaign
Dept. of Electrical and Computer Engineering

ECE 101: Computing Technologies and the Internet of Things

Sensing
(part 1 of 2)

Let's Move on to the Third Part of Our Course

Done with the second part of our course,

Intelligence and Implications!

Today, we start to discuss technologies that will mature in the immediate future.

These will define our future.
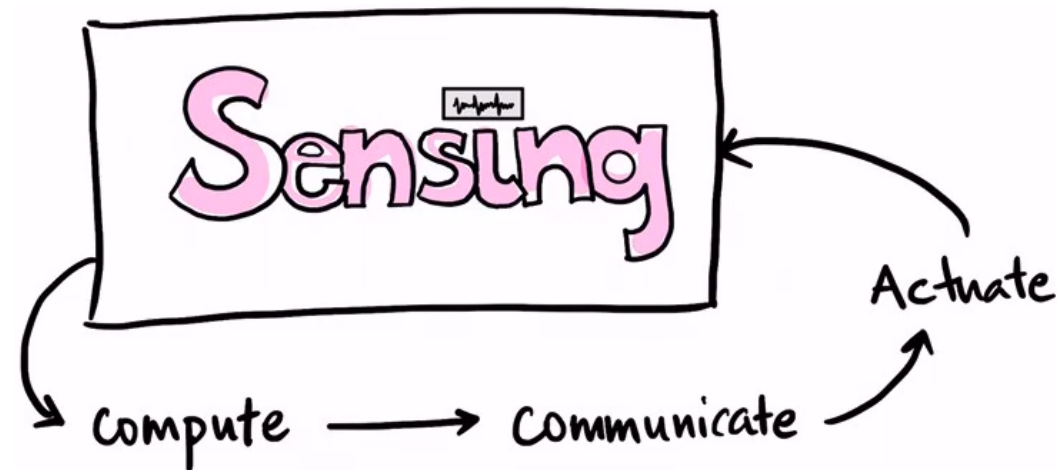
Theme: Sense-Compute-Communicate-Actuate Loop

We will discuss technologies coming soon to your home.

One common theme is the

sense-compute-communicate-actuate loop.

1. Do some sensing

2. Compute using sensed data

3. Communicate results
   to other systems/humans

4. Take action, changing the
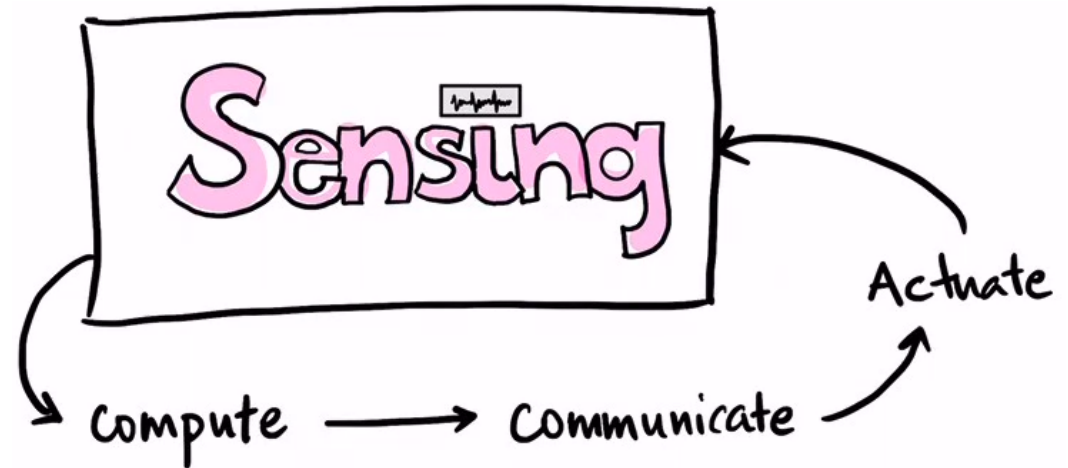   world

(start again)

Theme: Sense-Compute-Communicate-Actuate Loop

Actuation means that the machines control
something physical in the real world.

Once a machine
- actuates changes,
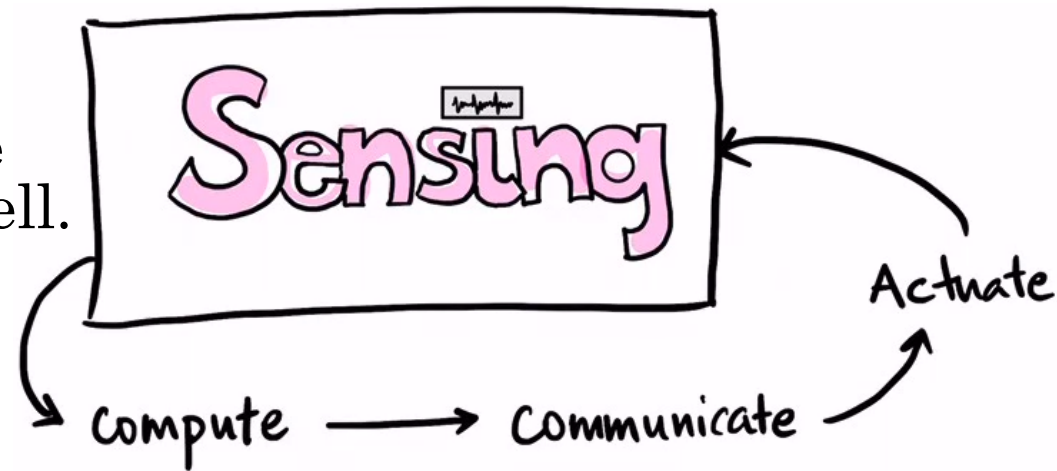- the machine must
  observe the results.

Theme: Sense-Compute-Communicate-Actuate Loop

For example, an omelet-making robot.

- The robotic hand puts pressure on an egg, and the egg cracks.

- The robot needs to notice that the egg has cracked and change action to separating the contents of the egg from the shell.

Figuring out how to do so smoothly is a challenge.

Theme: Sense-Compute-Communicate-Actuate Loop

We want "smart" machines.

Humans use a similar process in everything we do.

Sensing through
- ° eyes,
- ° ears,
- ° touch/feel,
- ° taste, and
- ° smell

Theme: Sense-Compute-Communicate-Actuate Loop

Computing happens
in the brain.

It's separated into parts:
  ° visual cortex,
  ° auditory cortex,
  ° somatosensory cortex,
  ° motor function,
  ° and more

Theme: Sense-Compute-Communicate-Actuate Loop

- Once the brain makes a decision,

- we communicate through facial expressions, motions, gestures, voice

- finally, we may actuate the hand muscles to do a high five.

     8

Theme: Sense-Compute-Communicate-Actuate Loop

Can we replicate that process (the loop)?

Can we get the robot to do a high five?

What happens next?

Do the loop again!

(actually happening continuously)

Boston Dynamics humanoid robot Atlas

Example: Emergency Drone Deliveries

Technology need not be humanoid.

Consider a drone that drops off emergency supplies after a catastrophic event (these exist now).

What are the elements of the loop?

- **Sense:** environment conditions, location via GPS
- **Compute**: process sensed data, decide what to do
- **Communicate**: with other drones/sites)
- **Actuate: c**ontrol rotors to land safely or hover, deposit package safely.

Start over—go get another package!

https://youtu.be/jEbRVNxL44c?si=9LcGYzW5fbnVffJF

Example: Autonomous Vehicles

- **Sense:** surroundings (Camera, LIDAR, GPS)

- **Compute**:

  - processing images, audio, video

  - identify objects

- **Communicate**: get more information

- **Actuate:** turn wheels, speed up, change lanes, turn signal, brake, basically drive the car

Loop continuously!

Example: Digital Agriculture / Robot Farmers (!)

Pick tomatoes only if they are ripe!

- **Sense**: appearance, softness

- **Compute**: ripeness.

- **Communicate**: desired ripeness threshold

- **Actuate:** pick the tomato without hurting the plant.

Loop—move on to next tomato/plant

Example: Digital Assistants (Alexa, Siri, Cortana, ...)

Sense: voice command (wake word)

Compute: speech to text

Communicate: with web/cloud/ customer cloud resources to get answers/information,

Actuate: transform results into human speech and output to speaker

Example: Cleaning Robots

These clean while mapping the rooms

Initially, the robot
- moves almost randomly
- to explore the house.
- once it has an idea of the layout and has created a map,
- it can use the map for more careful future movement.

Called **SLAM**: Simultaneous Localization and Mapping

Cleaning Robot: What are the Loop Elements?

Sense: distances to walls/obstacles

Compute:
° how long until collision given current motion direction + speed?
° build map of space (may need adjusting if you just bought a table!)
° what parts of the floor are clean?
° how can the robot reach parts that aren't clean (path planning, given dynamics of robot)?
° can it use a path that doesn't go over the same parts of the floor repeatedly?

Cleaning Robot: What are the Loop Elements?

Communicate?

Maybe not, unless multiple robots
- are coordinating to clean a house
- without overlapping work,
- trading map information, and so forth.

Actuate: change directions, speed; move around (wheels, motor), clean (suction control)

Example: Smart Treadmill

What are the Loop Elements?

Sense:

Compute:

Communicate:

Actuate:

Example: Smart Treadmill

What are the Loop Elements?

Sense: how fast am I walking? What's my heart rate? Is my gait even?

Compute: answers to questions, calories burned, track your exercise plan

Communicate: to smart watch/activity trackers so that they share information

Actuate: control speed, control angle relative to floor, play music

Today: Let's Look at Sensing

We've talked about **computing**.

We've talked about **communication**.

Actuation gets into control and robotics, so we won't go too deeply into those topics …

Today, let's spend some time on **sensing**.
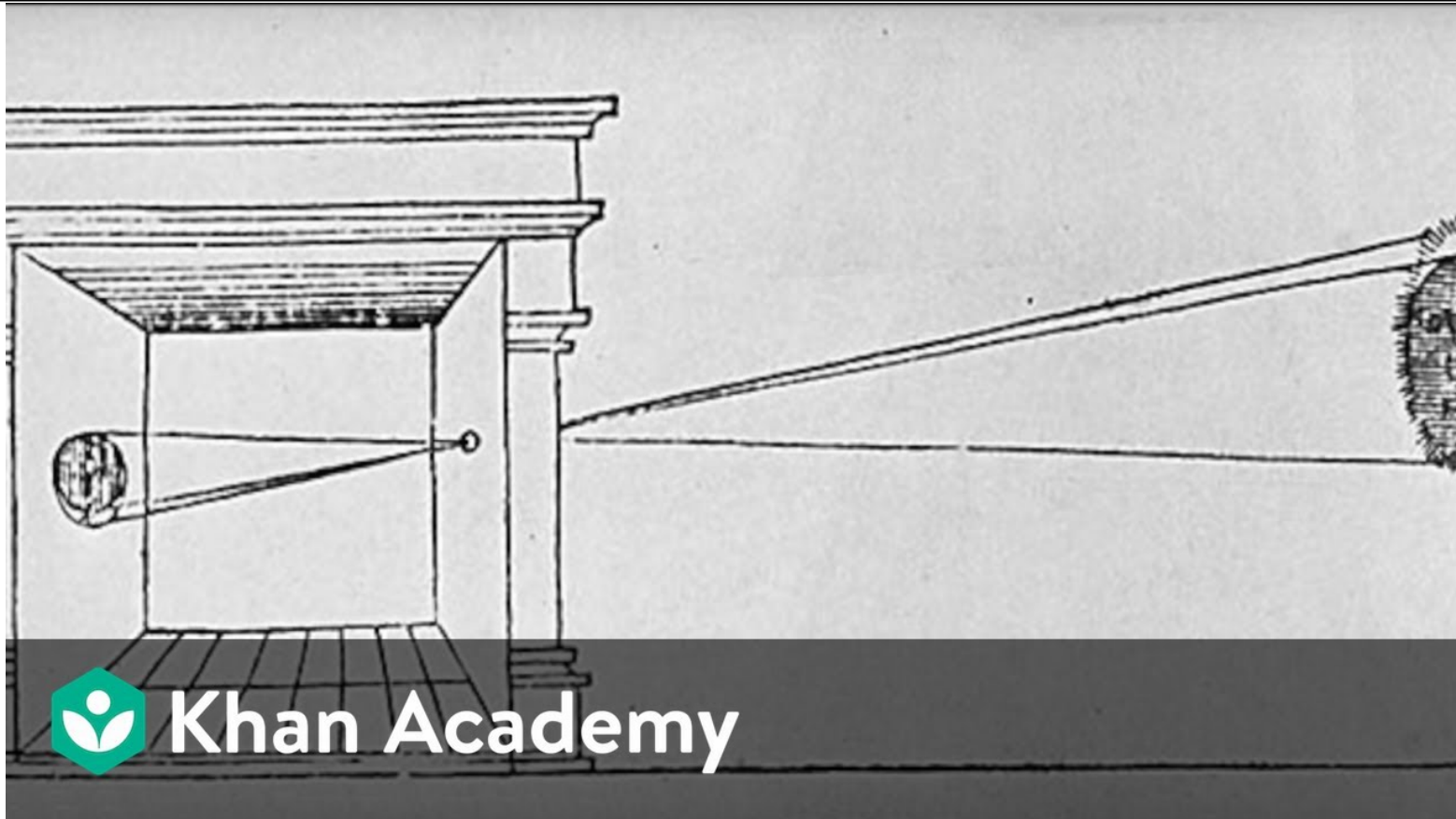
A Brief List of Sensors in Use Today

Types of sensors

1. **Cameras**: IR, thermal, radar, Lidar

2. **Microphones**: audible, ultrasound

3. **IMU**: **I**nertial **M**easurement **U**nit (accelerometer, gyroscope, magnetometer)

4. **Wireless**: GPS, Wifi (WiGig 60GHz, THz), UWB

5. **Assorted**: pressure, humidity, proximity, temperature, chemical traces
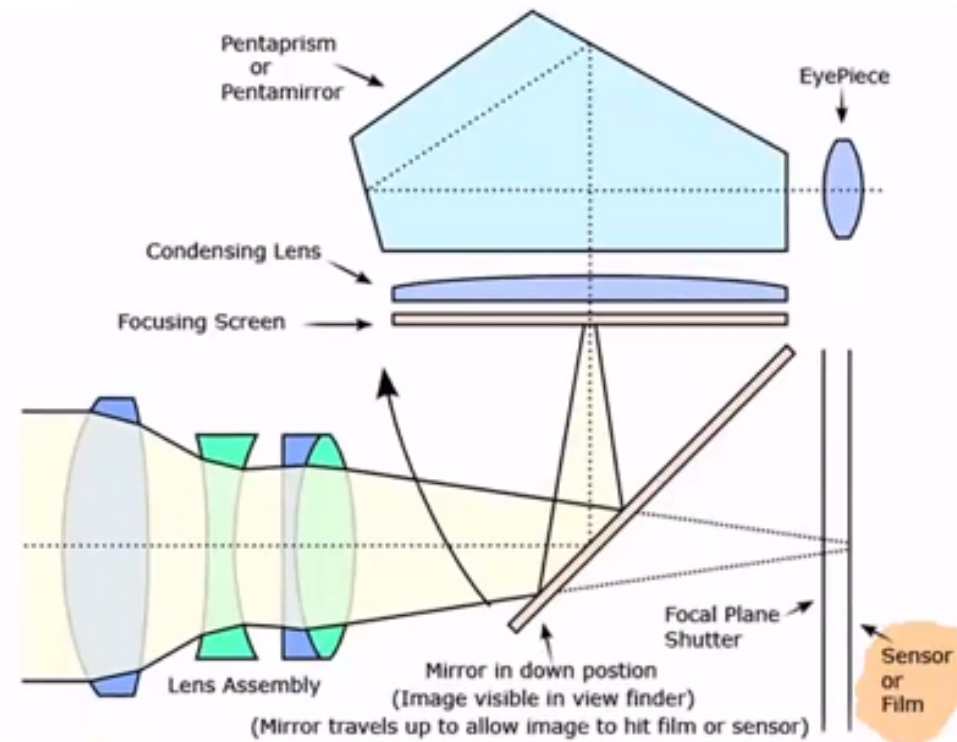
How Do Cameras Work?

Modern SLR Camera Operation

A modern "Single-Lens Reflex" (SLR) camera appears in the diagram to the right.

The mirror moves to enable the user to "see" what image will be captured on the sensor/film.

Today, light on the sensors produces electrical current, which is recorded.

Pentaprism or Pentamirror

EyePiece

Condensing Lens

Focusing Screen

Lens Assembly

Mirror in down postion
(Image visible in view finder)
(Mirror travels up to allow image to hit film or sensor)

Focal Plane Shutter
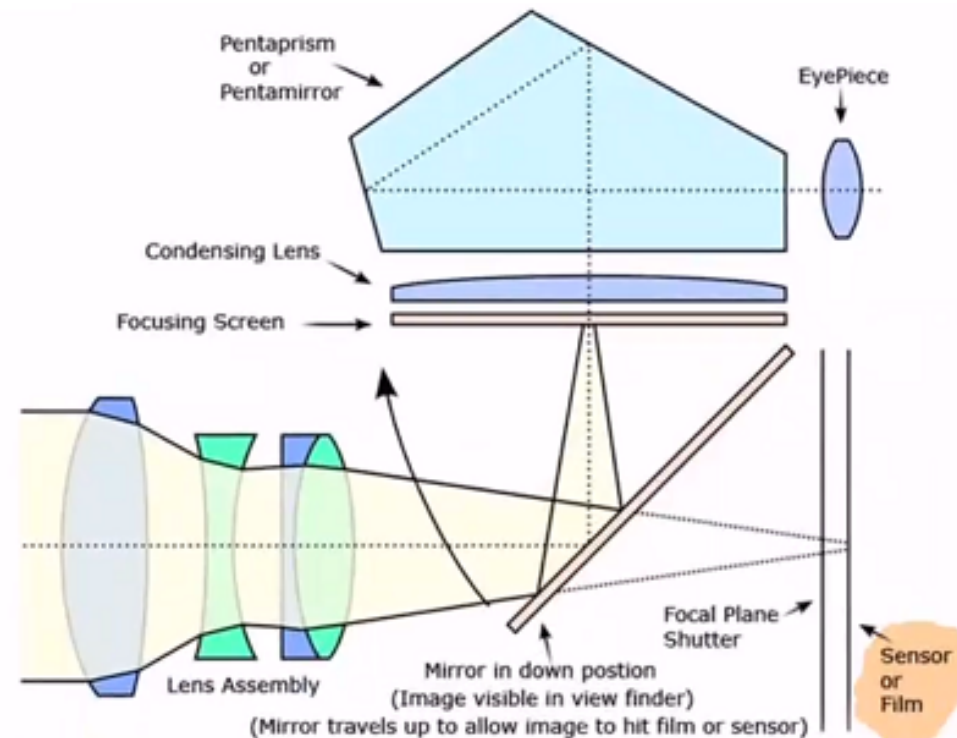
Sensor or Film

Arrays of Sensors Have Replaced Film

Sensors are tiny today:
single microns (10^{-6} meters).

Each dimension has thousands of pixels (square to obtain several Megapixels).

So an entire array is a few millimeters on a side.

Lenses focus outside image down to a few millimeters.

(Larger sensors capture more light more quickly, and
are used in more expensive cameras.)

Pentaprism
or
Pentamirror

EyePiece

Condensing Lens

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Lens Assembly

Mirror in down postion
(Image visible in view finder)
(Mirror travels up to allow image to hit film or sensor)

Focal Plane
Shutter

Sensor
or
Film

Smartphone Cameras Use a Prism for Compactness

In a smartphone camera, the light is first reflected by a prism, then passed into a set of lenses, and finally focused on the sensor array.

The image seen by the sensor array is reproduced on the phone screen (rather than using a separate viewfinder).
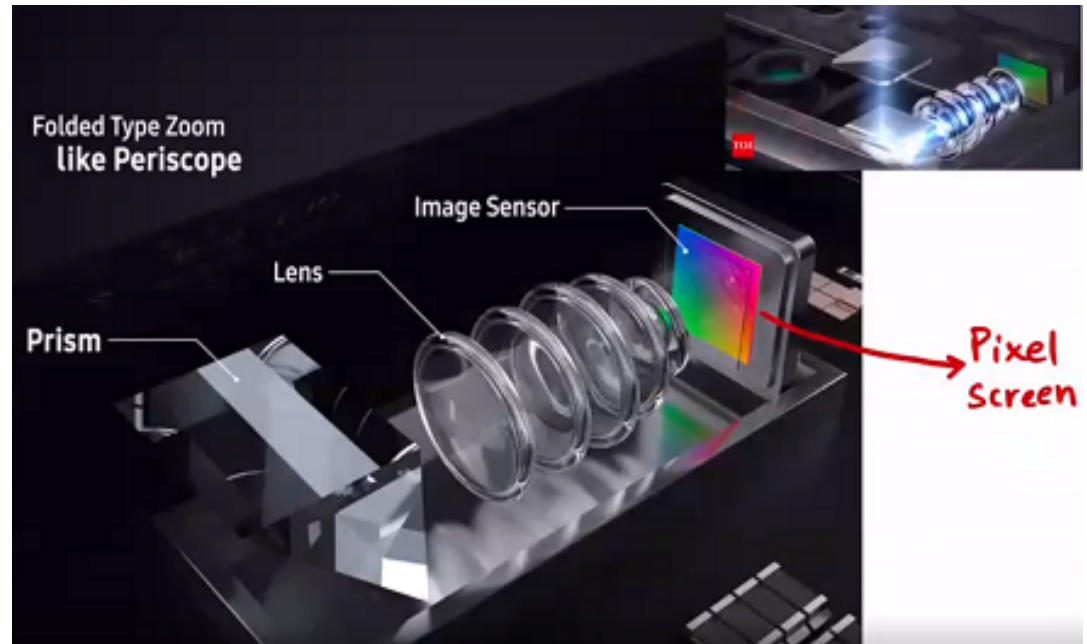
Terminology You Should Know from These Slides

° sense

° compute

° communicate

° actuate

° sense-compute-communicate-actuate (SCCA) loop

° sensors

° SLAM: Simultaneous Localization and Mapping

° pin-hole camera

° smart-phone camera

Concepts You Should Know from These Slides

- how the sense-compute-communicate-actuate (SCCA) loop operates to support "smart" machines
- relationship of the SCCA loop elements to humans
- examples of SCCA loop used in technologies
- examples of types of sensors
- basic operation of cameras and light sensor arrays