UNIVERSITÀ DEGLI STUDI
DI MODENA E REGGIO EMILIA

# Lecture notes for
# Multimedia Data Processing

## Image Capture Tools

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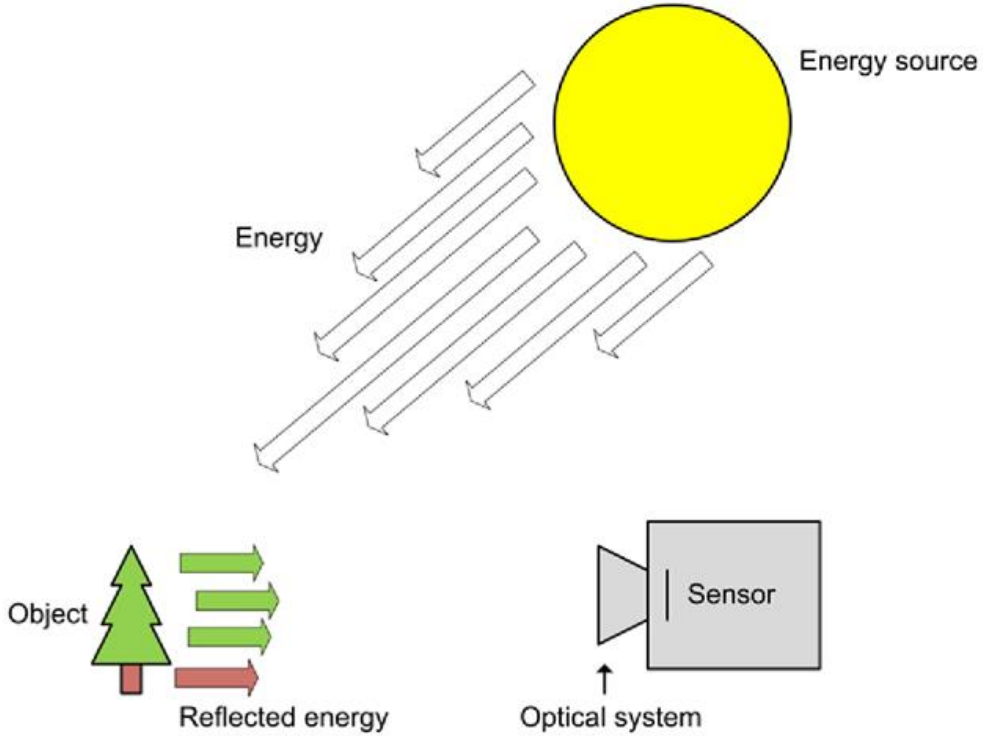
# IMAGE CAPTURE

# Image Acquisition

- The image is acquired by **digital sensors** capable of measuring and capturing the amount of photons that reach them (the light). The sensor surface is made up of tiny *photosites* arranged in a regular grid (spatial sampling). These *photosites* are micro-sensors that convert photons into electrons. The analog-to-digital converter (ADC) produces the numerical information.
- They are divided into two main construction technologies: **CCD** and **CMOS**



# Digital Image

- A **pixel** embodies each of the point elements that compose the representation of a digital image.
- The **resolution** indicates the density of the elementary points (*dot*) that return the image, in relation to a linear dimension. For example PPI (pixels per inch).
- **Quantization** is necessary because each pixel is represented with a finite number of bits.

Low resolution image

Original image

Image with low number of bits per pixel

# CCD (Charge-coupled Device)

- Solid state sensor invented in 1969 at the Bell Labs by Smith and Willard.
- The following year a working prototype was made. Boyle and Smith were awarded the Nobel Prize for Physics in 2009 for their invention.
- In 1975, the first CCD video camera was made with enough image quality for TV shots.

- Amplification, ADC and processing outside the sensor.

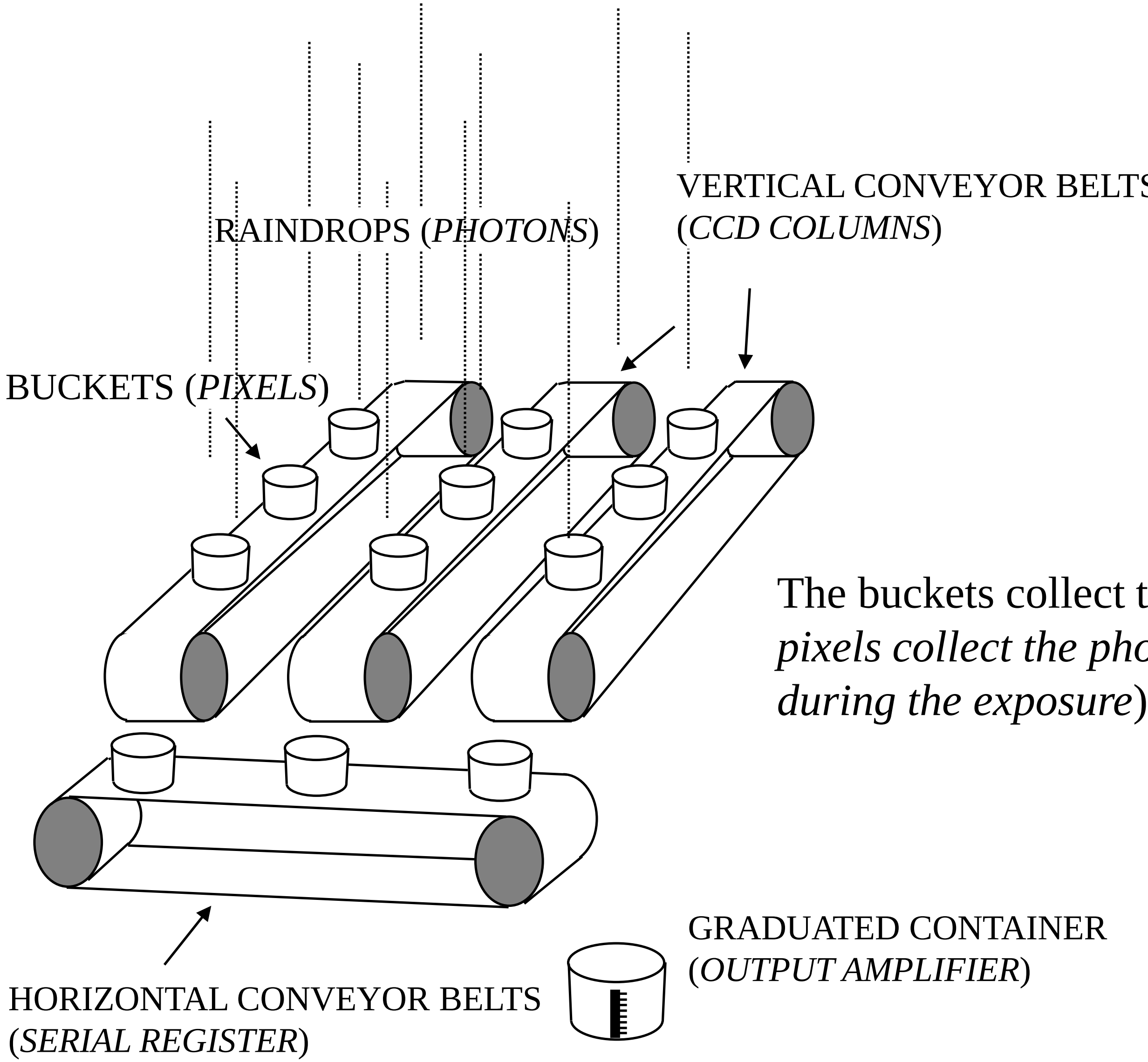
- High quality images (up to 100% fill factor), low noise (charges zeroed at each reading)
- Special production process → Expensive !!
- Main types:
  - Linear
  - Full frame transfer
  - Frame transfer
  - Interline transfer

# CCD - Photons and raindrops

In order to understand how a CCD works we can resort to this simple analogy between photons and raindrops:

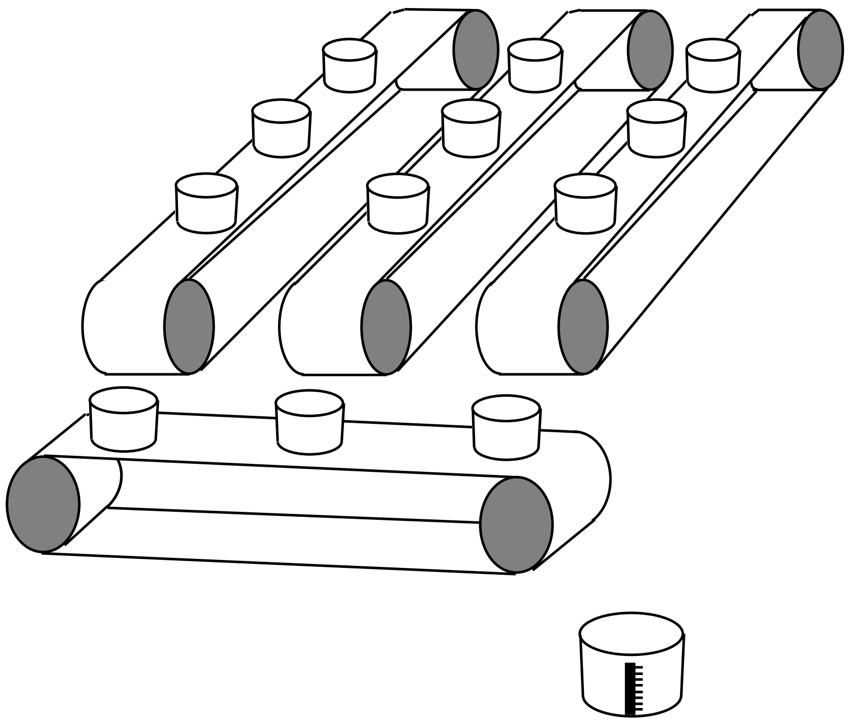
Some buckets (*pixels*) are distributed in a field (*sensor focal plane*) and are placed on a series of conveyor belts (*CCD columns*).
The buckets collect the rain (*photons*) that falls on the field. The conveyor belts are initially stopped. The rain falls and fills the buckets (*exposure*).
After the rain (*closing the shutter*) the conveyor belts carry and put the water in a graduated container (*amplifier*) located in one of the corners of the field (*corner of the CCD*).

The next slides schematize the operation of the conveyor belts with an animation.

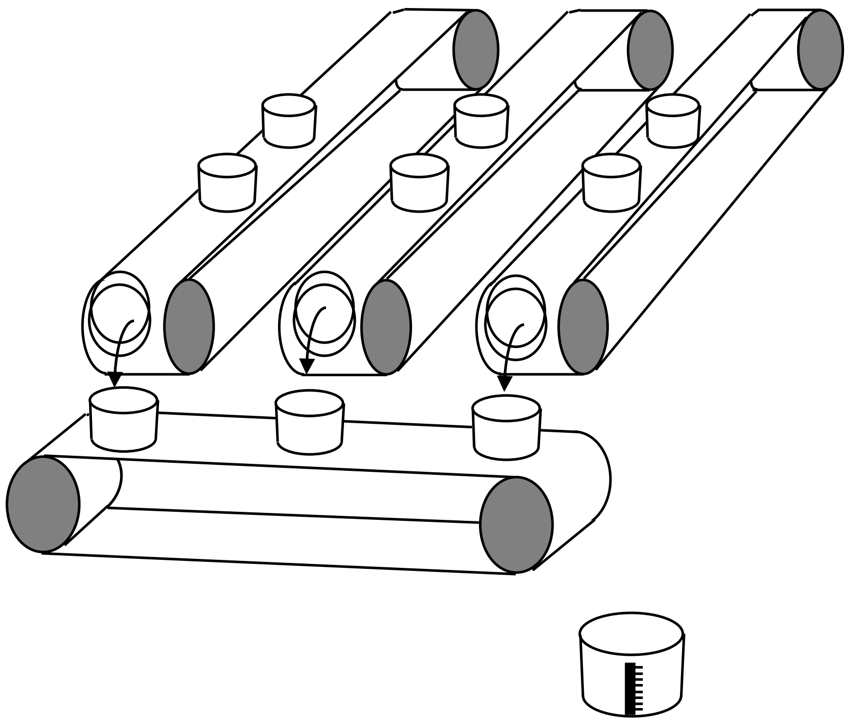



The buckets collect the rain (*the pixels collect the photons during the exposure*)

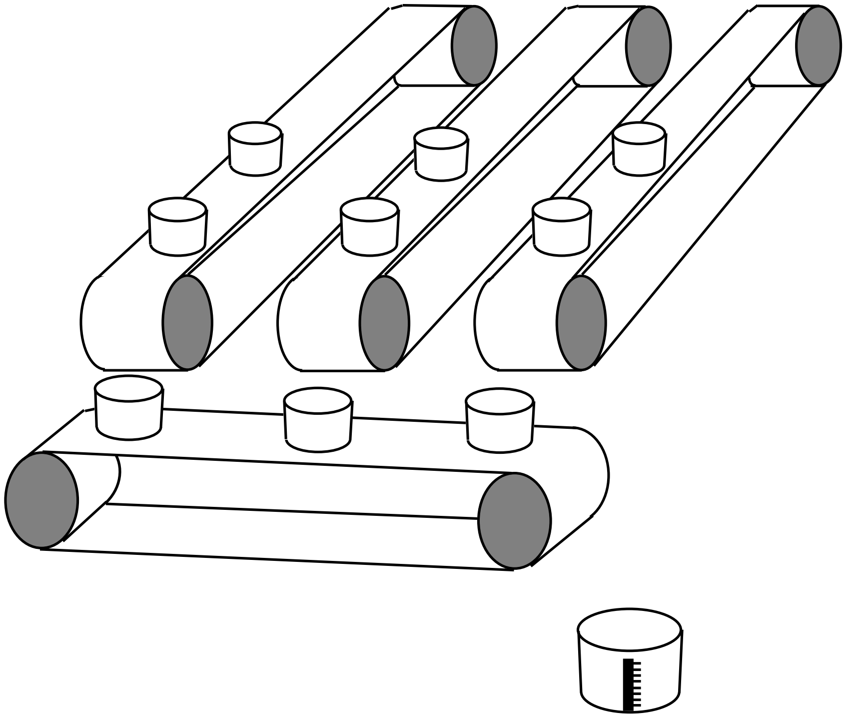
At the end, the buckets contain a certain amount of water (***at the end of the exposure the pixels contain a certain amount of charge***)



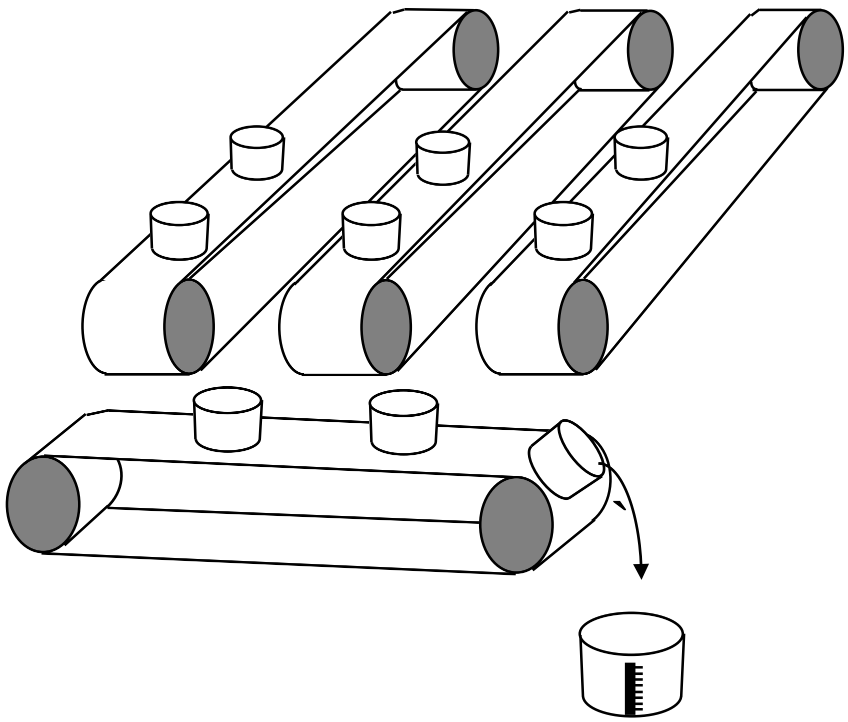
Conveyor belts start and move the buckets. The first row of buckets on the vertical belts is moved to the horizontal belt.

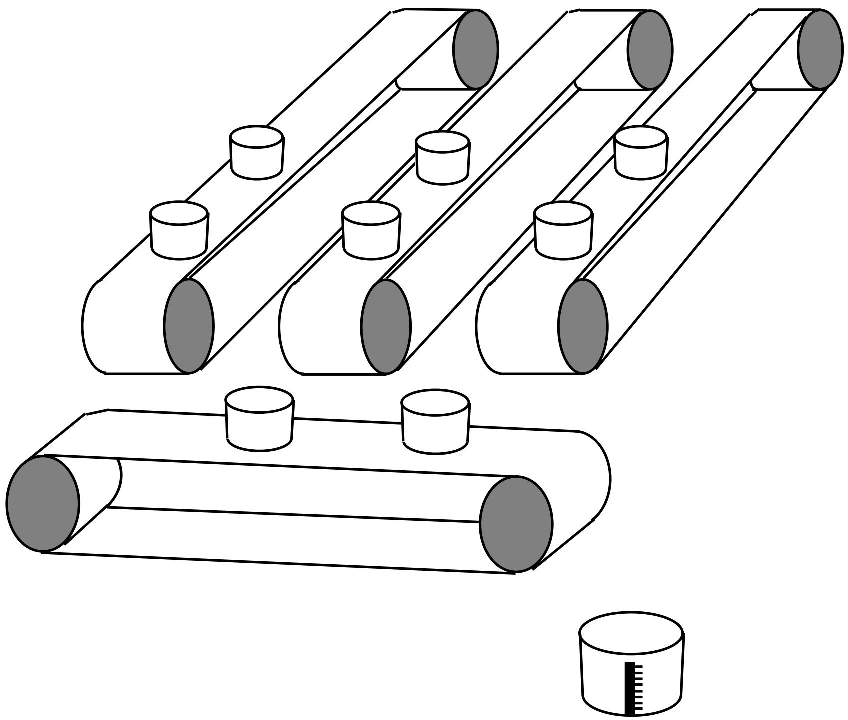


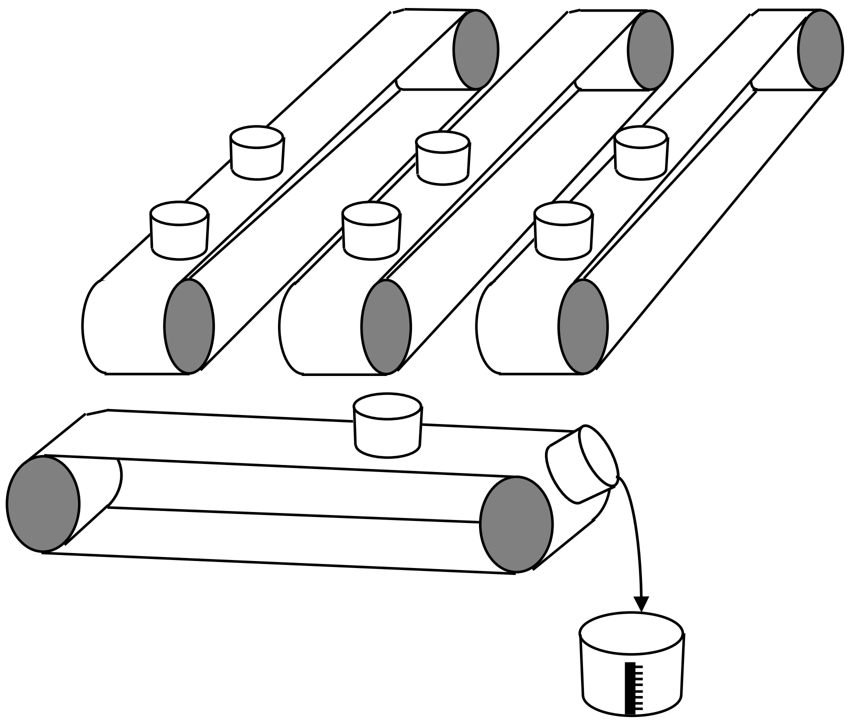
Vertical belts stop, while the horizontal one transfers the content of the first bucket into the graduated container.

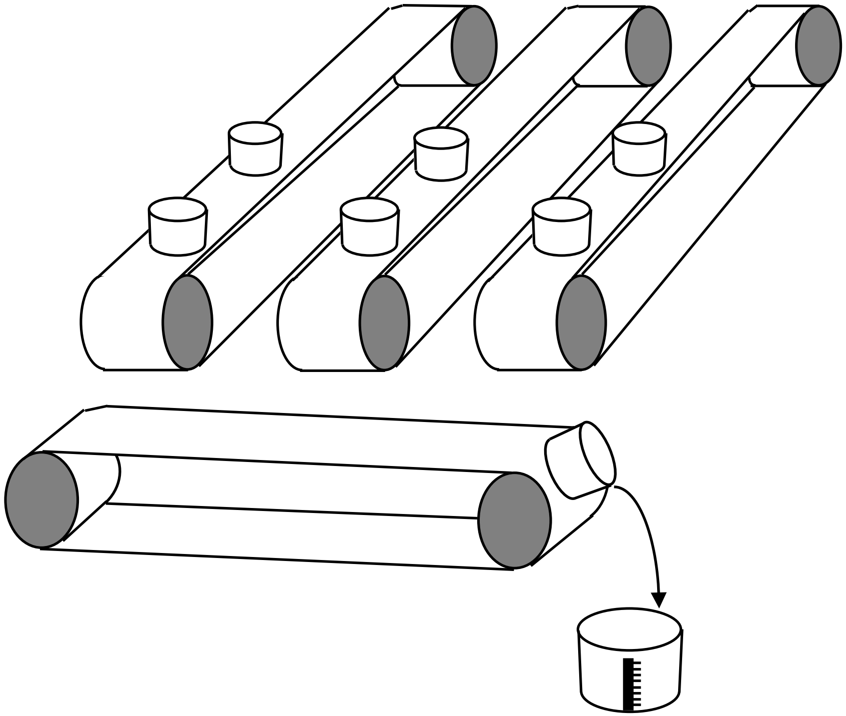


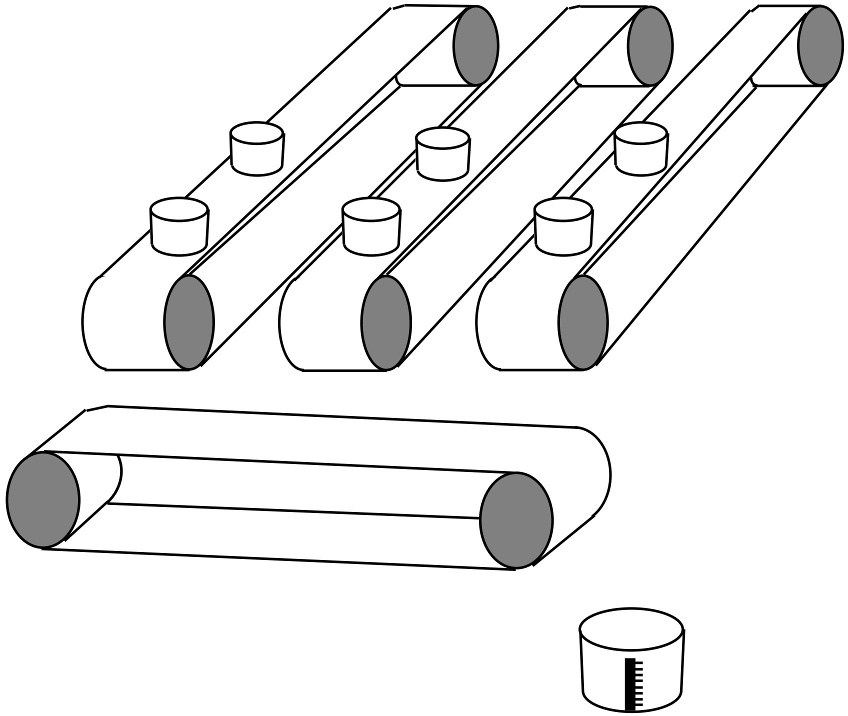
The water content of the first bucket is measured. The container is emptied and is ready to receive the water contained in the second bucket. The procedure is repeated for all the buckets in the row.



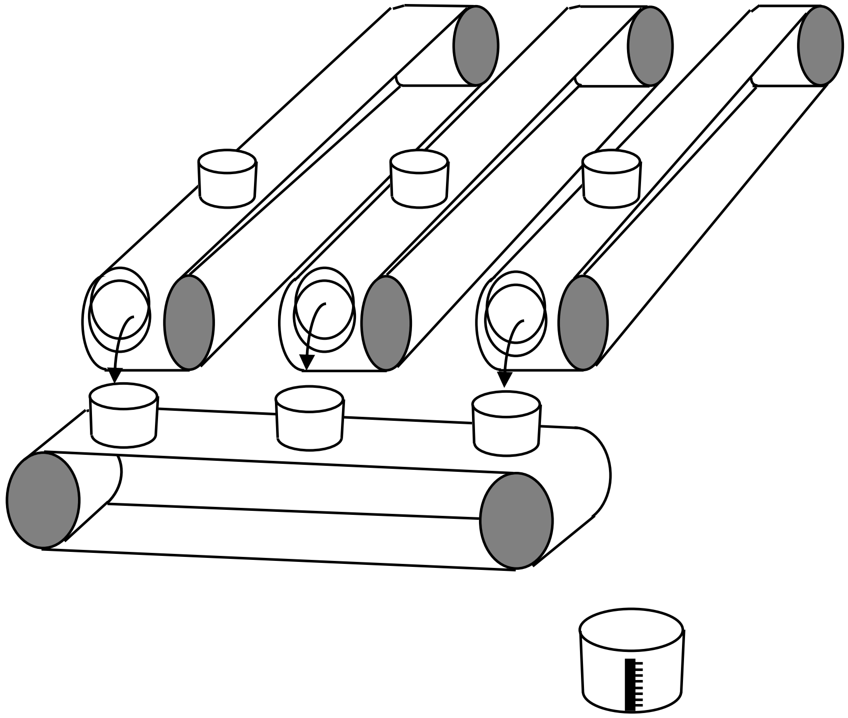


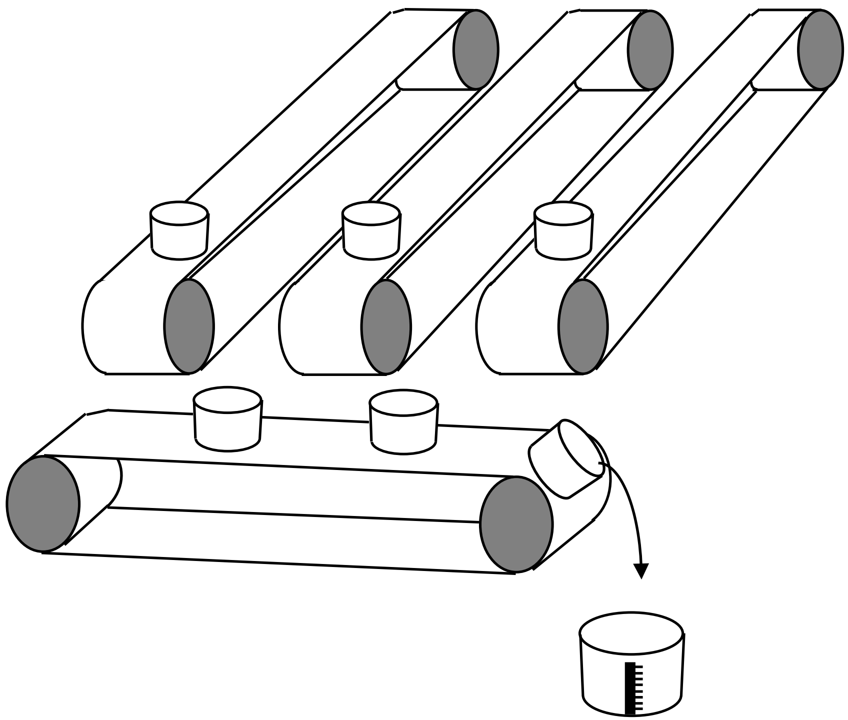


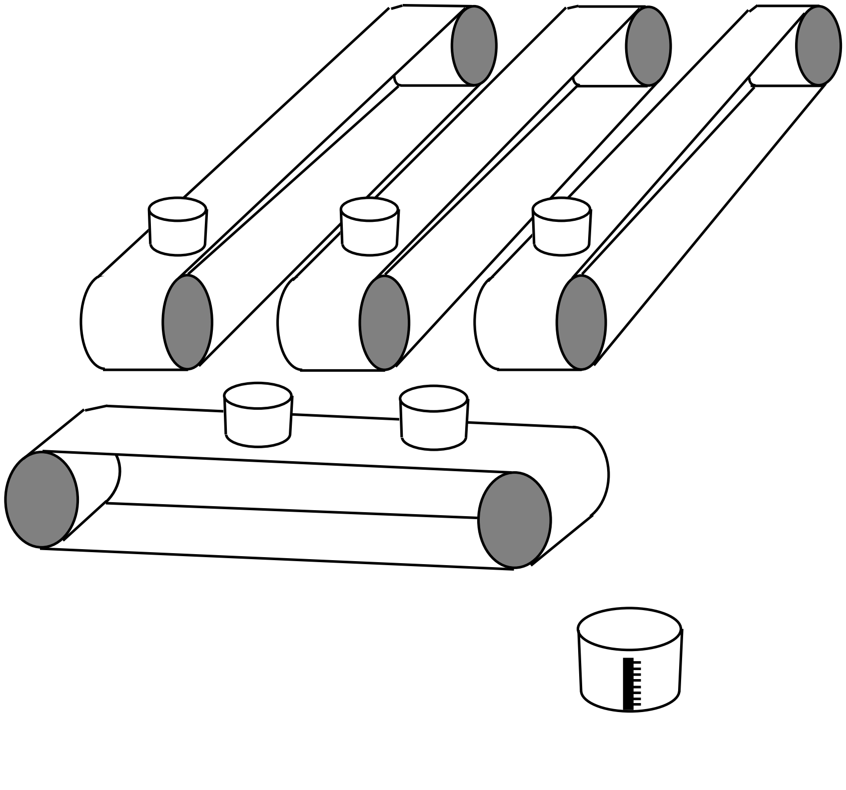


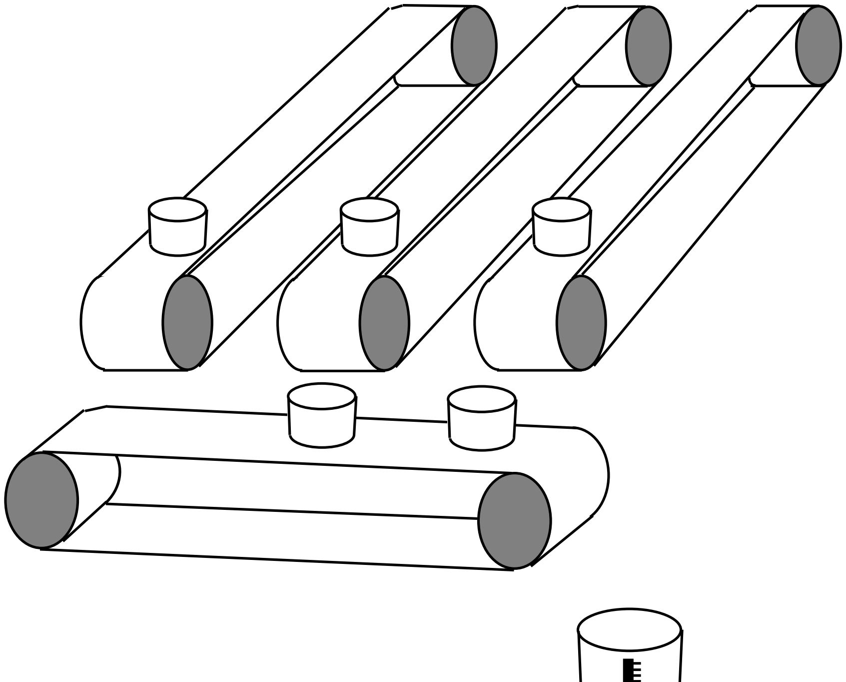


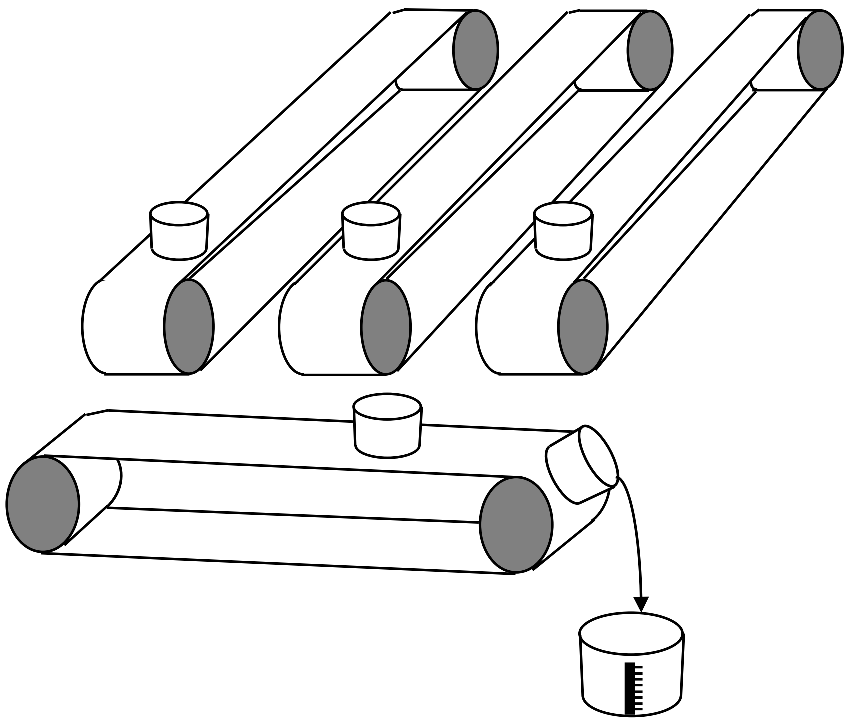
A new row of buckets is moved to the horizontal belt and the measurement procedure is repeated for all rows of buckets.

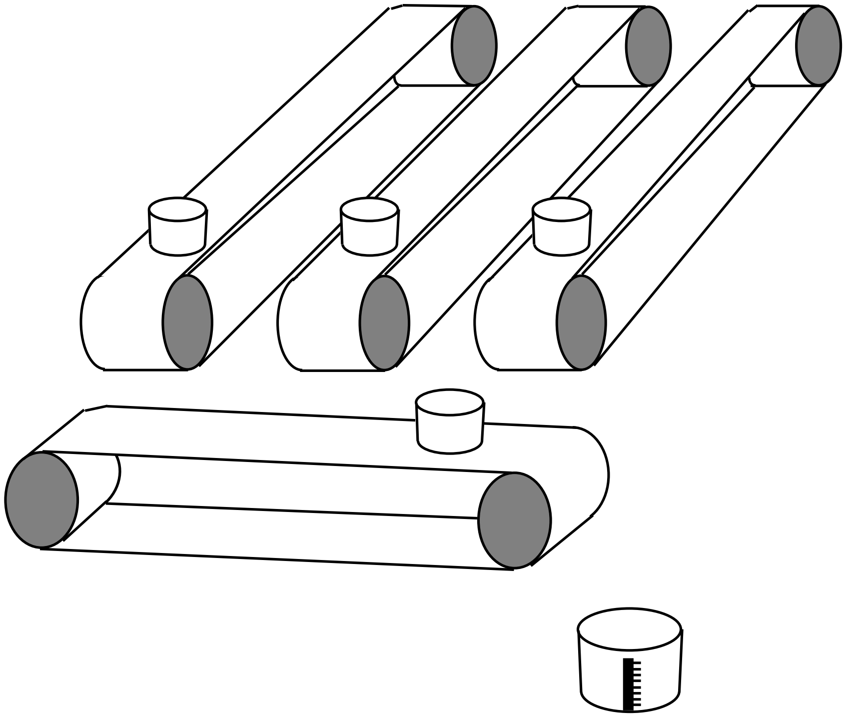


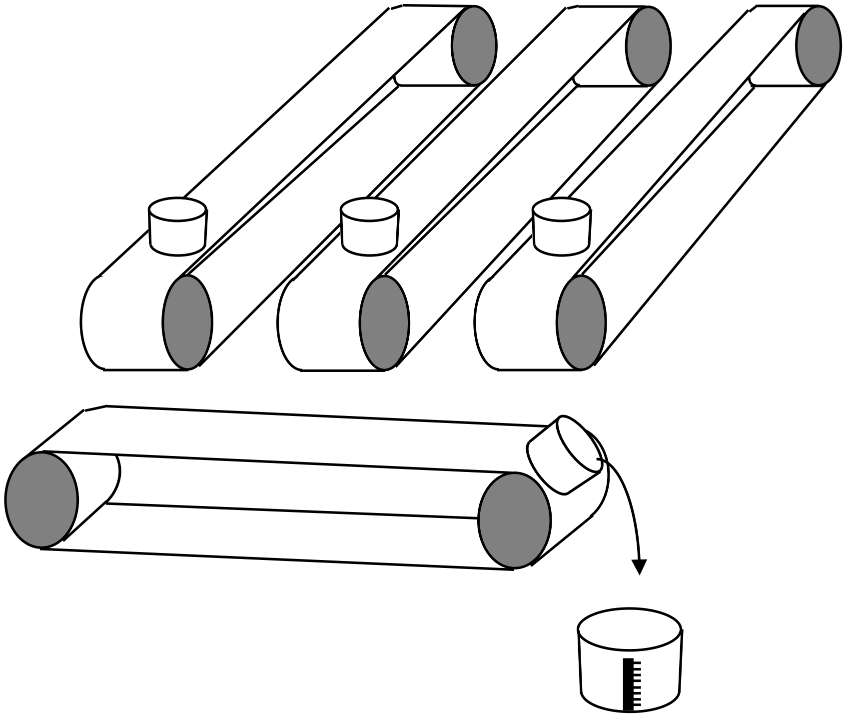


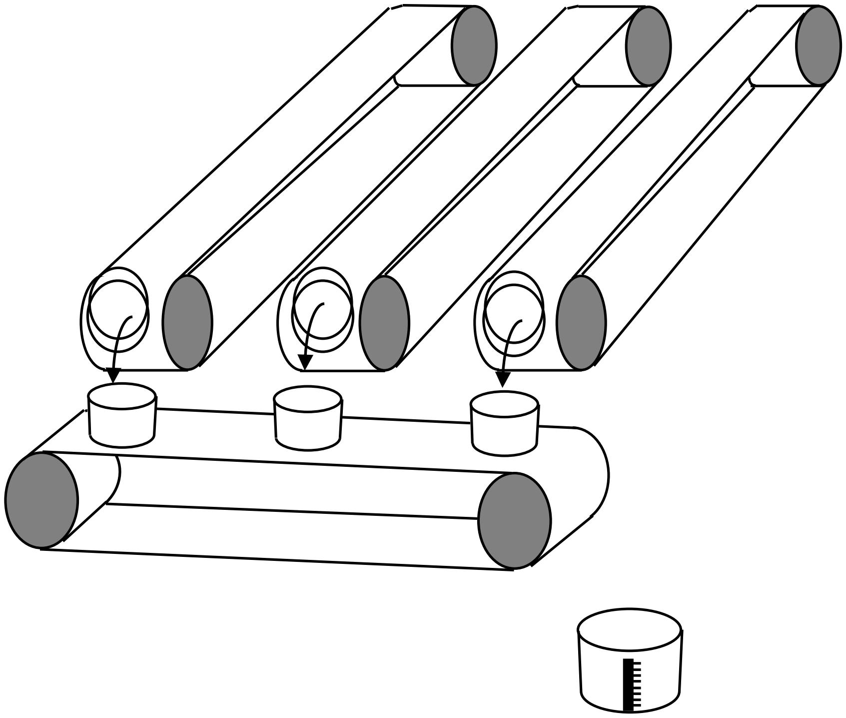


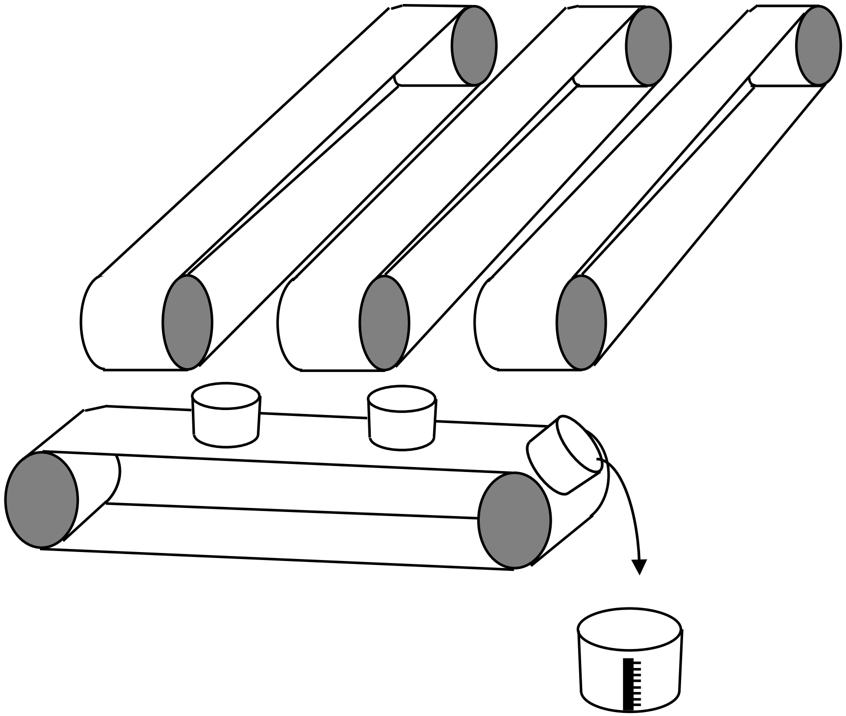


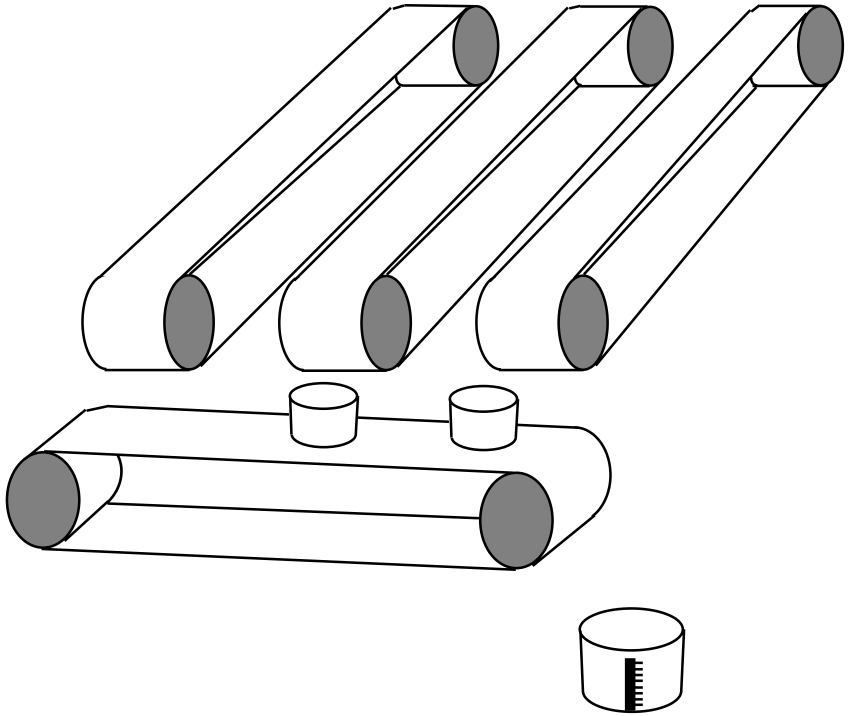


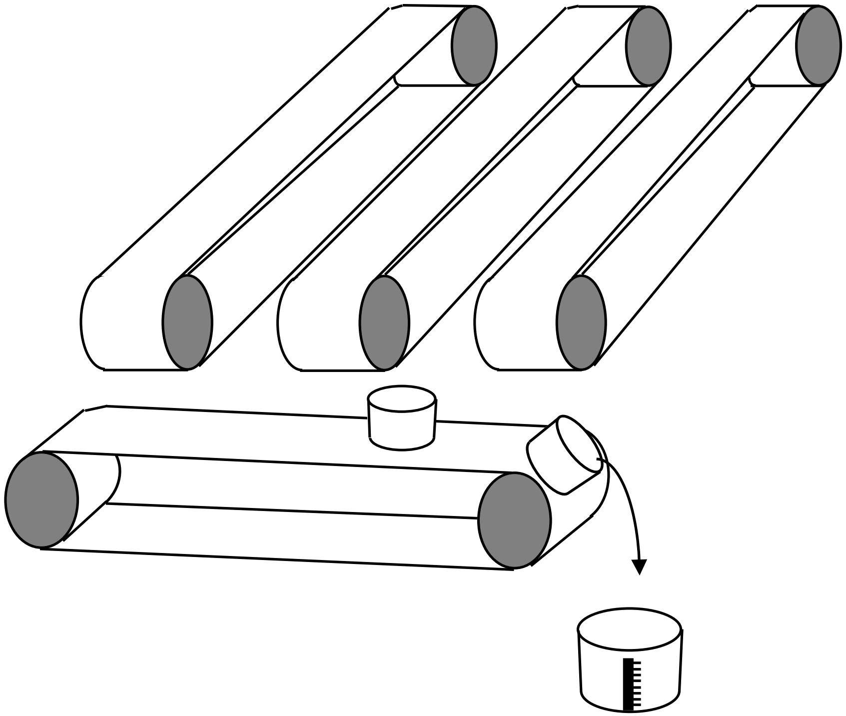


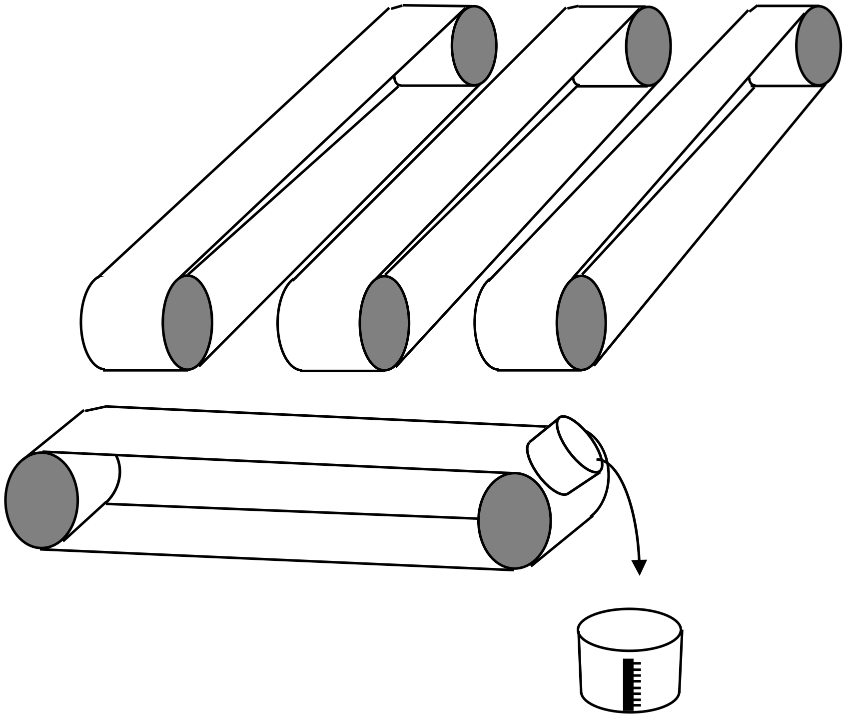




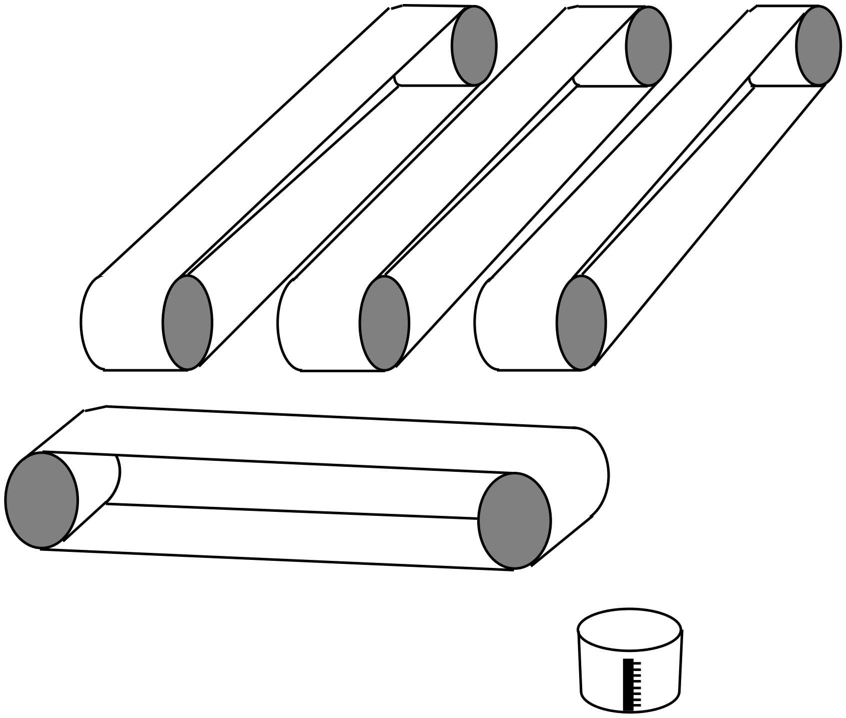






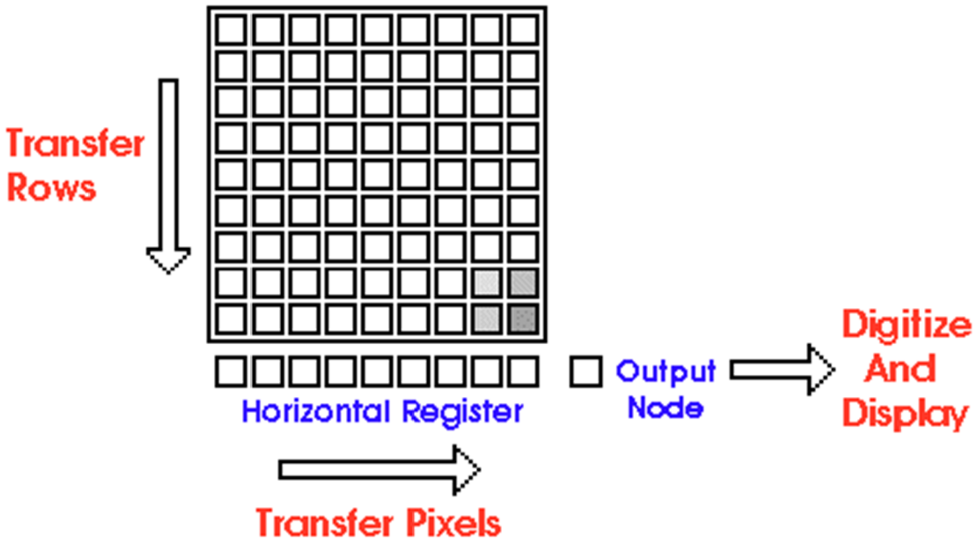


The CCD reading is complete when the content of all buckets has been measured.



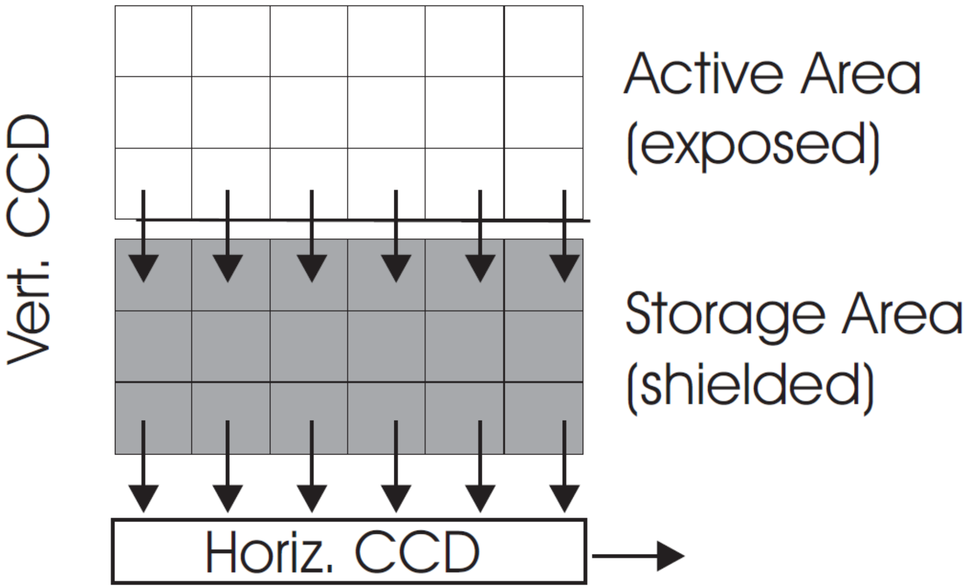
# Full Frame Transfer CCD

- Full Frame Transfer CCDs only have the active area.
- At the end of the exposure, the image is read by progressive vertical transfer of the sensor matrix lines content, from the first line to the last, from which the signal is taken and numerically sampled.
- This process typically takes a significant fraction of a seconds. If the sensor area is not protected from the incident flux of photons, the final image will be affected by **smearing**, i.e. a halo caused by the continuous absorption of light energy (need for electromechanical shutters).



# Frame Transfer CCD

- The sensor is composed of an active area and a storage area (not exposed to light). During the exposure time (also called integration time) the charge accumulates in the active area, creating the image of the scene.

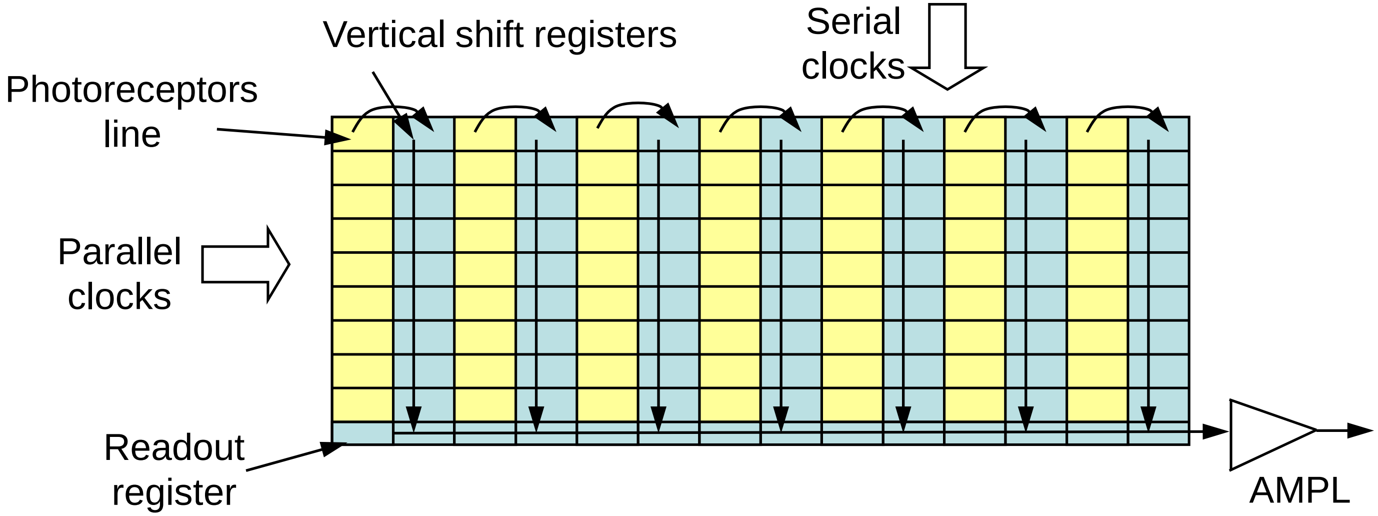



- The CCD Frame Transfer cameras do not need to be equipped with electromechanical shutters as the movement of the charges is extremely fast.

# Interline Transfer CCD

- The charges in the first row are transferred vertically to the readout register, which sends them to the amplifier and then to the ADC. Reading line by line.

- The **shift of the charges** from the pixels to the vertical reading registers takes just over a microsecond. Therefore, the cameras equipped with Interline Transfer CCD do not need electromechanical shutters.

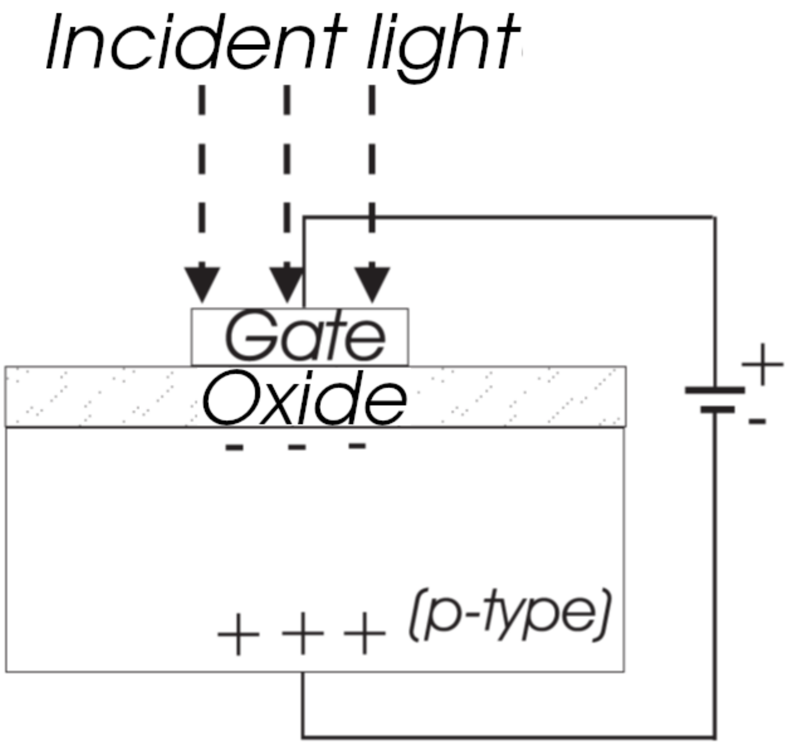


# Interline and Full Frame Transfer CCD Comparison

- Interline (IT) sensors have a much shorter transfer time from the active area to the storage area than Full Frame Transfer (FFT).
- The FFT sensors instead have a higher percentage of active area for each pixel (fill-factor), therefore a greater intrinsic ability to capture light.

# CCD

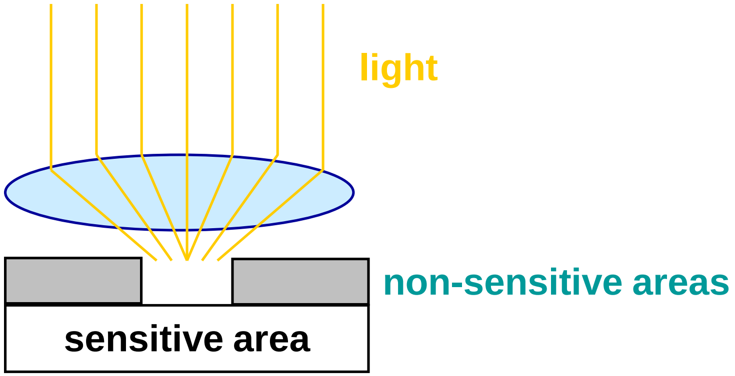
- The photosensitive elements of a CCD sensor consist of **MOS capacitors** exposed to incident light.
- The MOS capacitor is made by depositing a conductive layer on the wafer, which is placed over an insulating oxide layer.
- When a positive voltage is applied between the gate and the substrate, an electric field is generated in the area under the gate, which is able to attract electrons to the gate and to push holes towards the substrate.

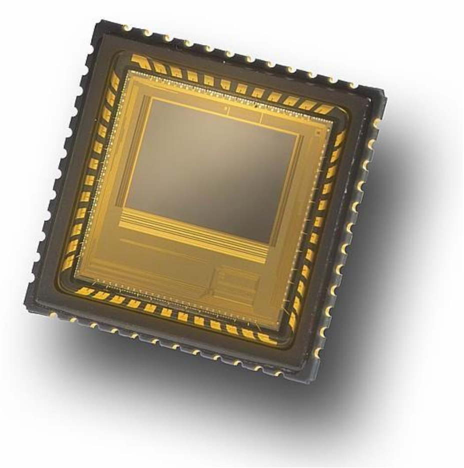



- There is also a certain amount of charge generated because of thermal energy (dark current).

# CMOS (Complementary metal–oxide–semiconductor)

- Invented before the CCD but little used until a few years ago.
- Same production technology as modern computer processors → greater integrability (micro sensors, smart cameras) and lower costs.
- Amplification, ADC and processing within each pixel.
- Greater acquisition flexibility (*windowing*, area selection).
- Sensitive to noise because silicon non-uniformity (amps with different characteristics) → Compensation circuits based on the characteristics of the single chip are used.
- Fill factor < 100% (more space for circuits).
  - Use of microlenses (more than in CCD).



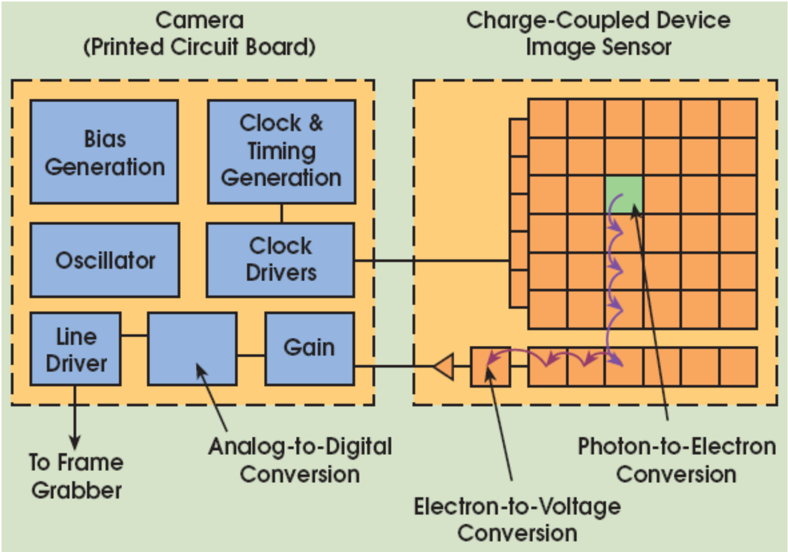



- Low power consumption ($\frac{1}{100}$ of CCD) → portable devices (smartphone, PDA, …).
- Lately high quality CMOS are used in the professional field.

# Schemas

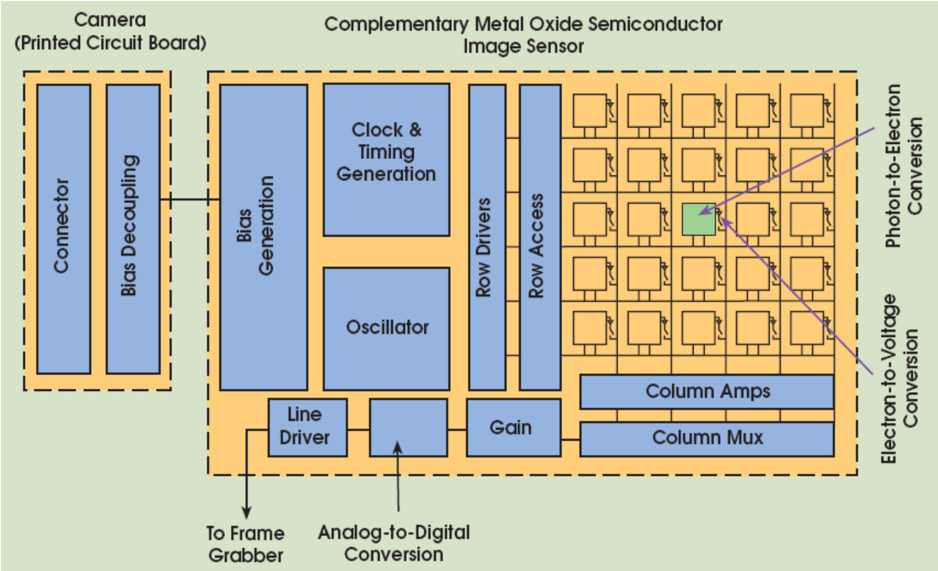
**CCD:**

- The chip only contains the sensors and the electron to voltage conversion.
- Higher polarization voltage and external clock.
- If the application changes, just change the external electronics without redesigning the sensor.




**CMOS:**

- Most of the electronics are inside the chip.
- Single clock level and polarization voltage (bias).
- If the application changes, the sensor must be redesigned.



# CCD VS CMOS

- The main differences are:
  - **CCD creates a high quality image** and low noise level, while CMOS is more susceptible to noise.
  - **CCD consumes a large amount of energy**, while CMOS, which consumes less energy, overheats less and introduces less noise.
  - **CCD** type sensors **are more expensive** than CMOS.
  - **CMOS sensors have a greater construction complexity** than CCDs.
  - **CMOS sensors offer more integration** (we find them in smarphones cameras).

Great technological efforts (CMOS for quality and CCD to reduce power consumption) have made them very similar.

**Poor lighting:** CCD has more uniform behavior, because it is a unique amplifier.

**Electronic shutter** is the ability to start and stop light capture (important for CCD sensors).