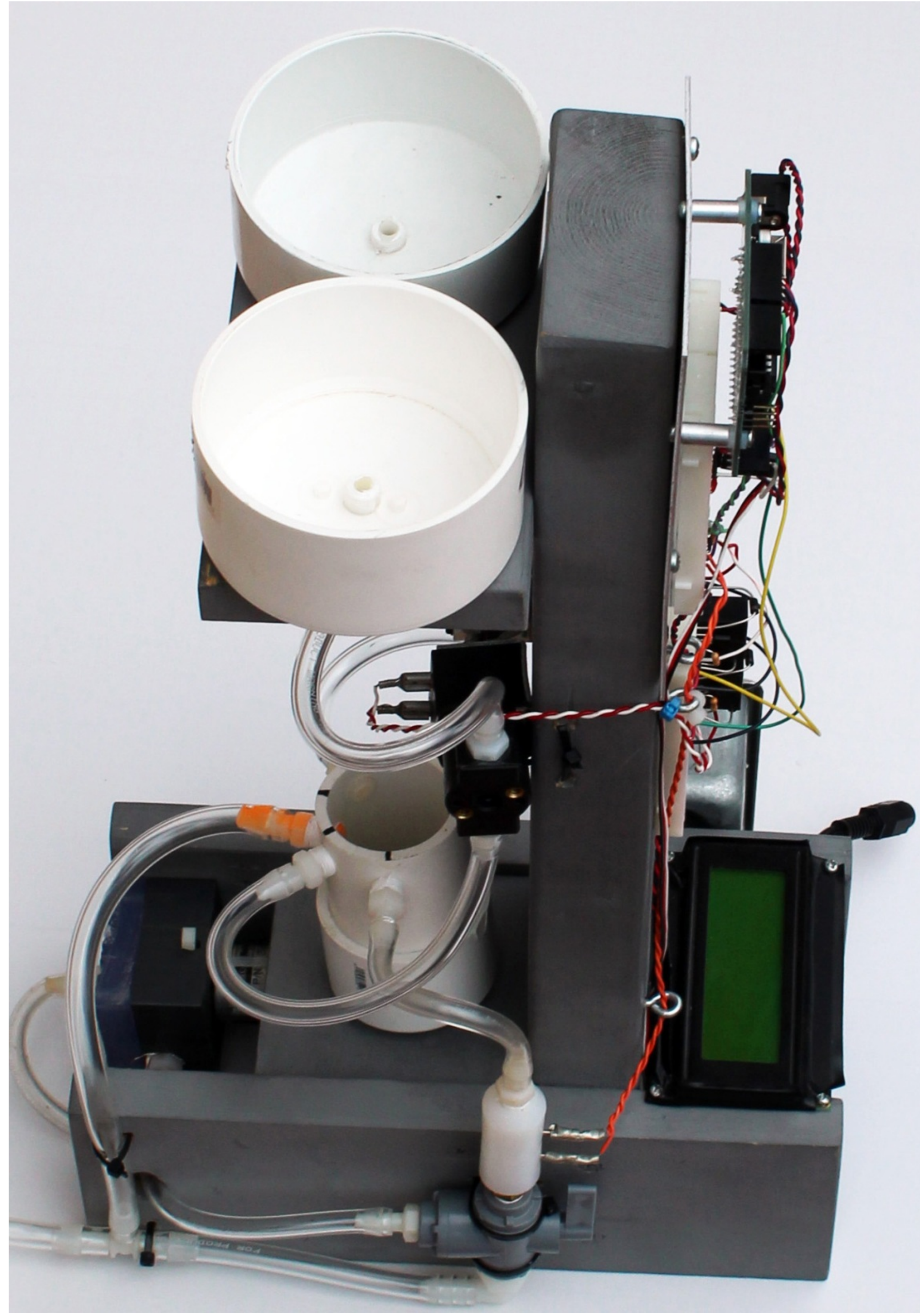
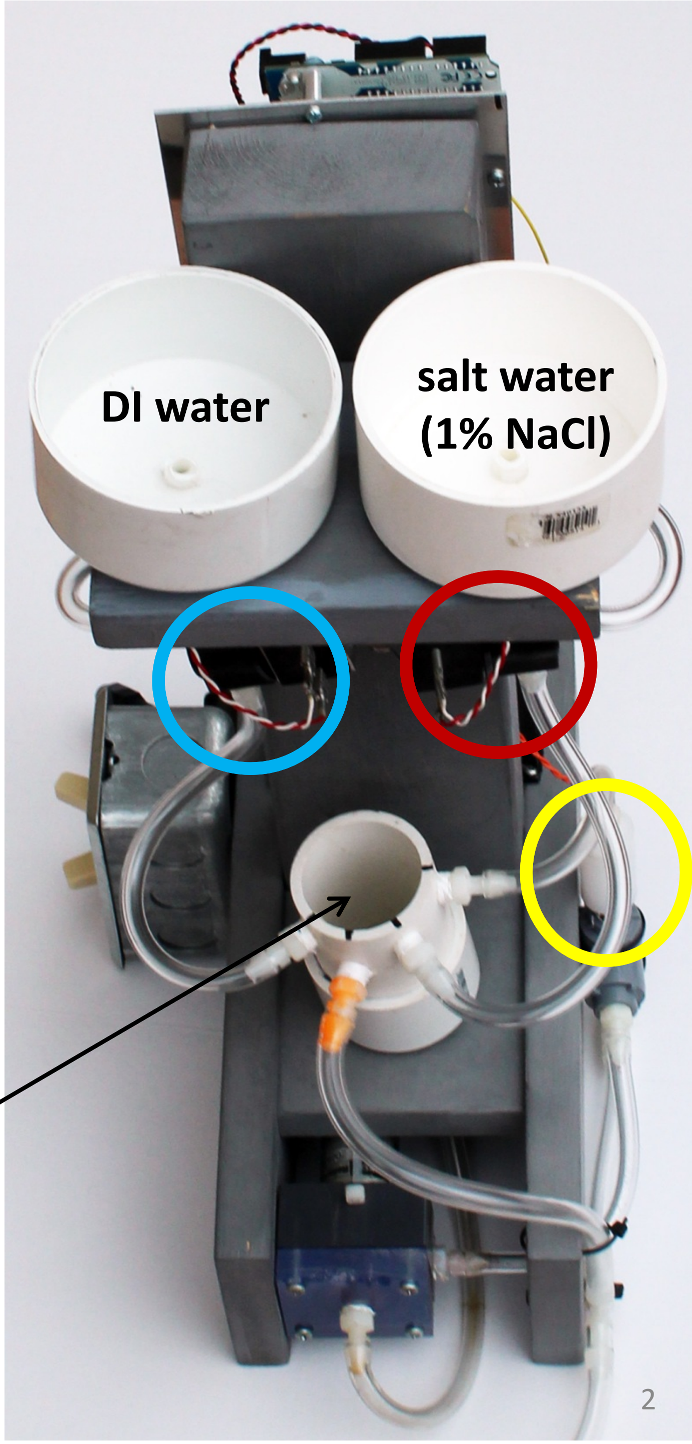
control of salinity



General Idea

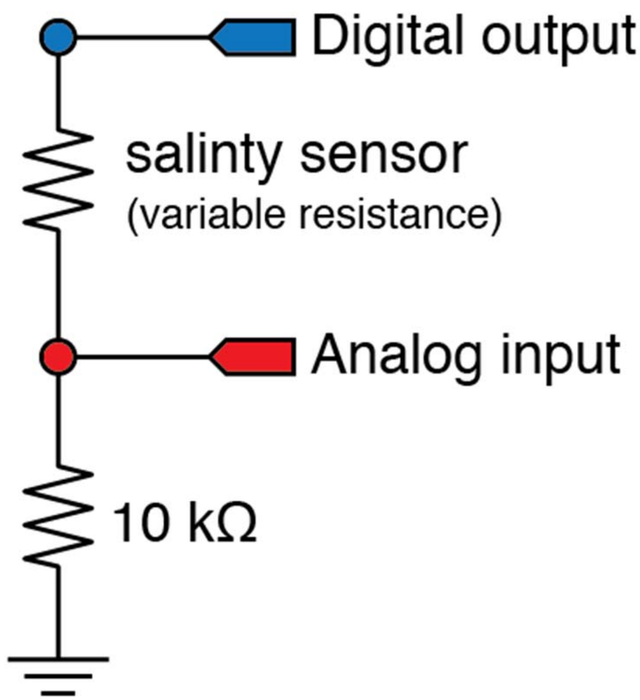
- The objective is to keep the salinity close to a **setpoint** which will provided by your instructor
- The salinity sensor measures the analog voltage output of the salinity circuit
- Opening DI solenoid valve decreases salinity
- Opening salty solenoid valve increases salinity



0.05 wt % NaCl ≤ setpoint for salinity ≥ 0.15 wt% NaCl

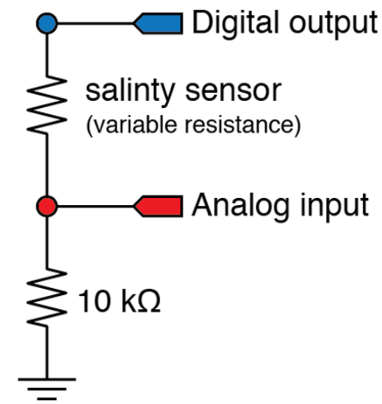
(your instructor will provide a setpoint, such as 0.09 wt% NaCl)

review of conductivity sensor wiring & programming




```
//  Averaged salinity sensor reading

int power_pin = 3;

void setup() {
  Serial.begin(9600);
  pinMode(salinity_power_pin, OUTPUT);
}

void loop()
{
  int   input_pin = 2;      //  Analog input pin
  int   nave=20;            //  Number of readings to average
  float reading_ave;        //  Average Value returned from function

  reading_ave = salinity_reading( power_pin, input_pin, nave);
  Serial.println(salinity_ave);
}
```

review of conductivity sensor wiring & programming

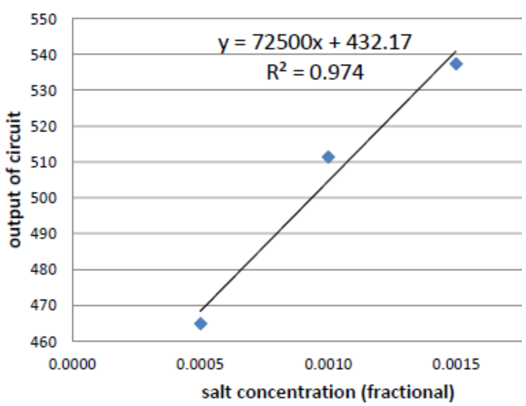



```
// -- Perform averaging of sensor readings

float salinity_reading_average( int power_pin, int input_pin, int nave ) {

  int   i;
  float sum;  //  Use float for more precision and to prevent overflow of sum

  sum = 0.0;
  digitalWrite( power_pin, HIGH );    //  Supply power to the sensor
  delay(50);                          //  Wait for sensor to settle
  for ( i=1; i<=nave; i++ ) {
    sum += analogRead( input_pin );   //  Add reading to the running sum
    delay(10);                        //  Pause between readings
  }
  digitalWrite( power_pin, LOW );     //  Turn off power to the sensor
  return( sum/float(nave) );
}
```

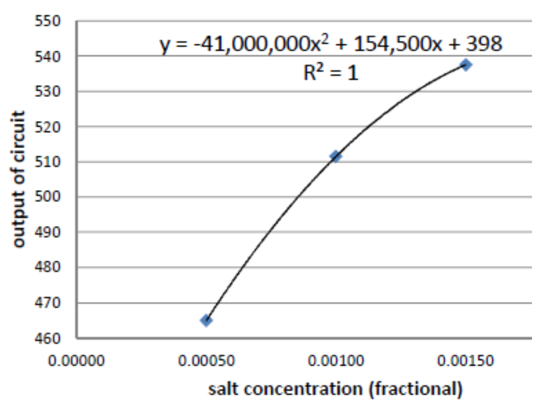
review of conductivity sensor calibration

- Collect analog output of salinity circuit, with output numbers ranging from 0 to 1023 (the Arudino has a 10-bit ADC)
- Perform linear regression to determine the expected output of the conductivity circuit as a function of salinity
- Which fit is the best?

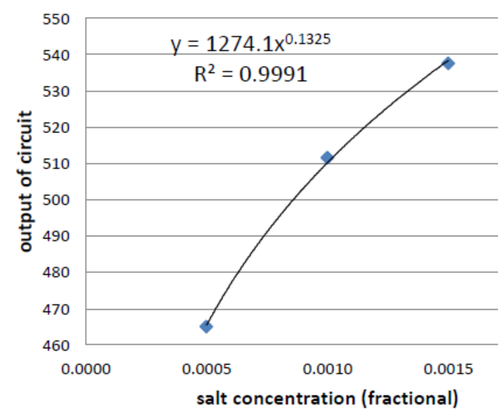
salt concentration (fractional)	Arduino output
0.0000	2.5
0.0005	465
0.0010	511.5
0.0015	537.5



linear



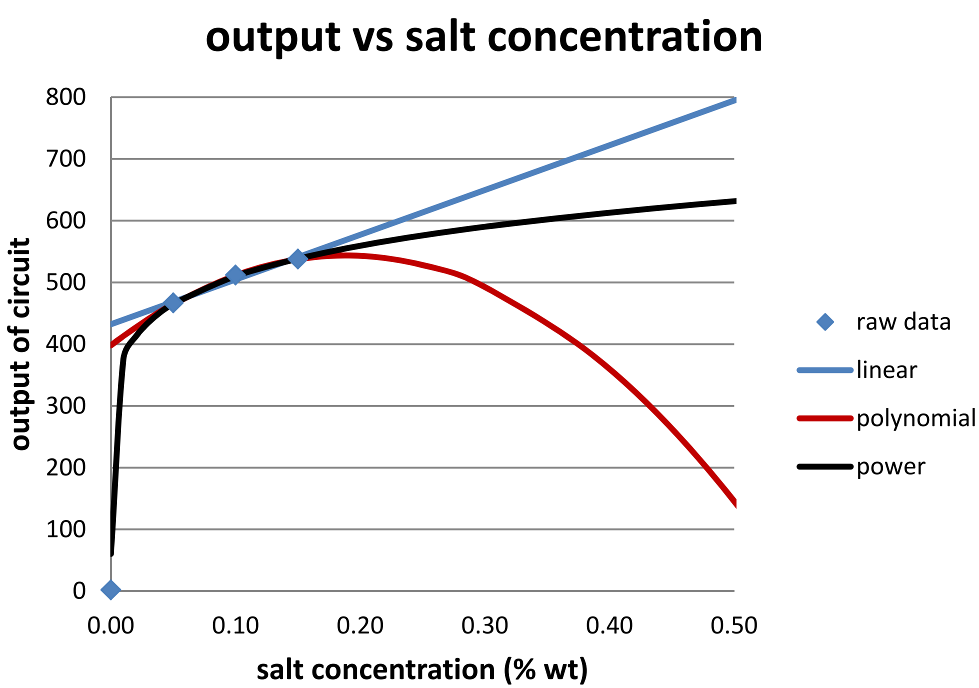
polynomial

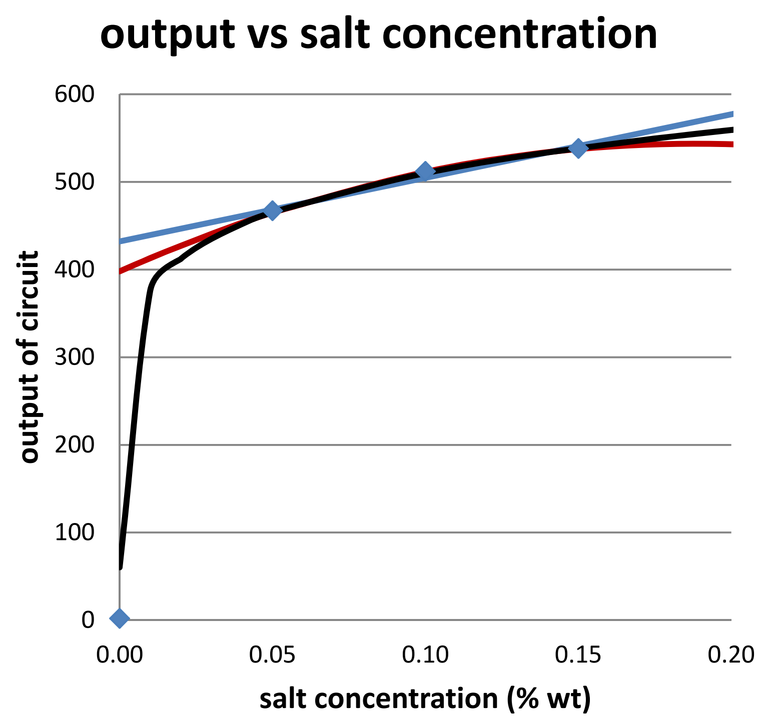


power

examine fits over possible salinity range

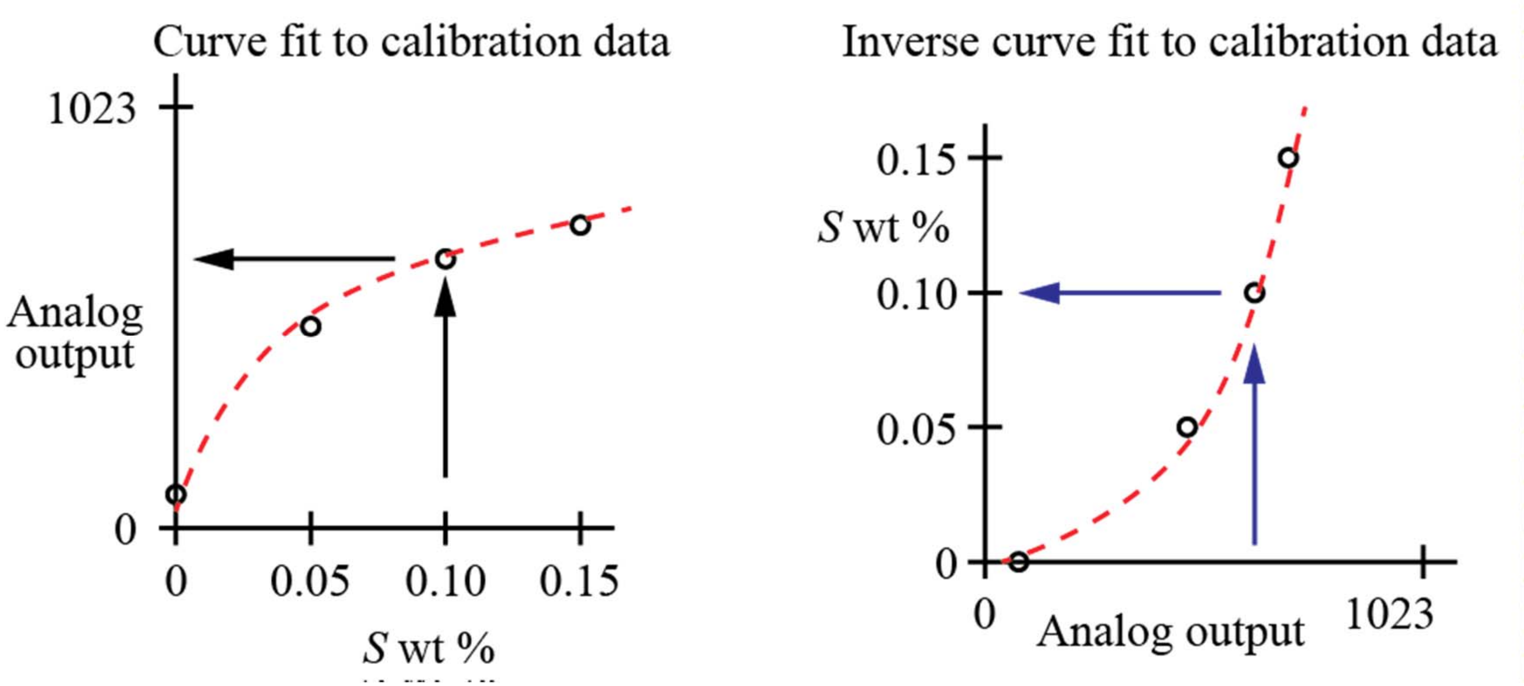
Consider how your fit behaves beyond 0.15 wt% salt since your salinity may increase well beyond 0.15% when salty water is added





- Do you see any potential problems?
- Which fit seems to be the best? Why?

equations needed for salinity control sketch



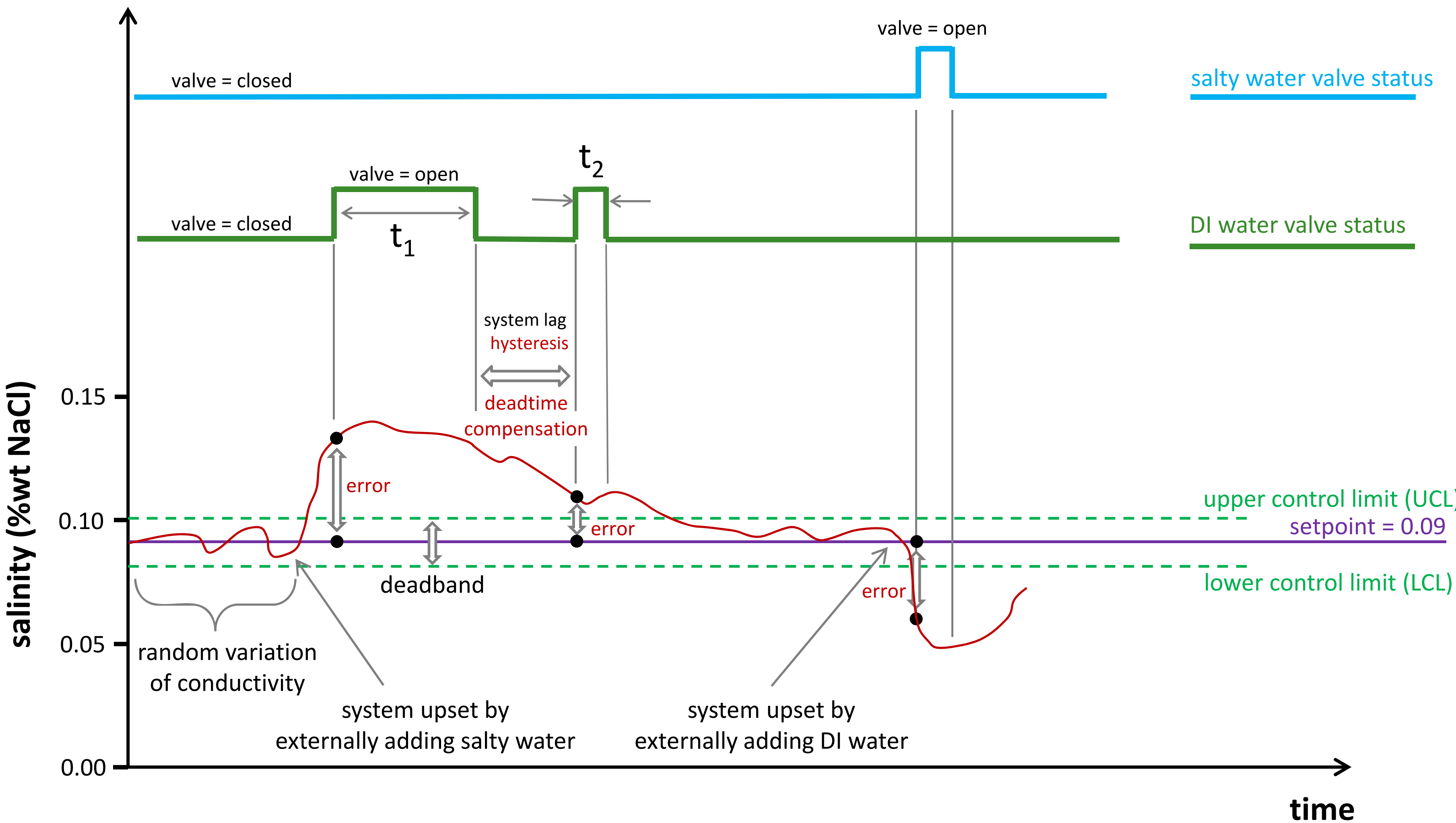
Inverse equation can be obtained by

- Algebraic rearrangement of the calibration curve fit, or
- Performing another fit with x and y values swapped.

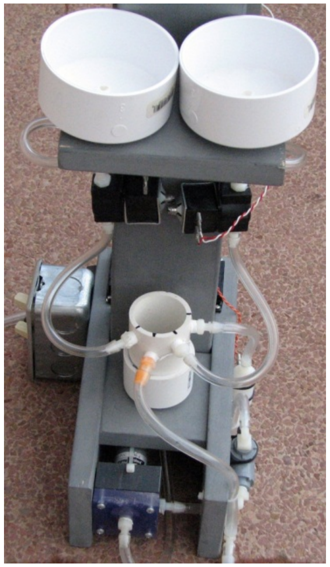
In either case, retain four or five digits in the curve fit coefficients

Control of Salinity

$t_1 > t_2$ since valve is left open an amount of time proportional to the **error**



key points



- The valve is left open an amount of time that is proportional to the error.
  - small error = valve is open a short amount of time
  - large error = valve is open a long amount of time
- The DI valve is left open longer than the salty valve when correcting for the same magnitude of error (DI=0%, setpoint = 0.09%, salty = 1%).
- The system has memory . . . it takes time for the salinity of the water to become uniform (mixing, water in pump and tubing). The lag time is called hysteresis.
- Control is more stable if we wait for the system to stabilize after opening a valve. The deadtime compensation is set to allow the system to come to equilibrium before responding to error.
- The upper and lower control limits are set so that random error will not cause the valves to open unnecessarily; these limits are often set three standard deviations of the error away from the setpoint. The difference between UCL and LCL is called the deadband.

control strategy

- The setpoint will be assigned by your instructor. Assume 0.09% NaCl here.

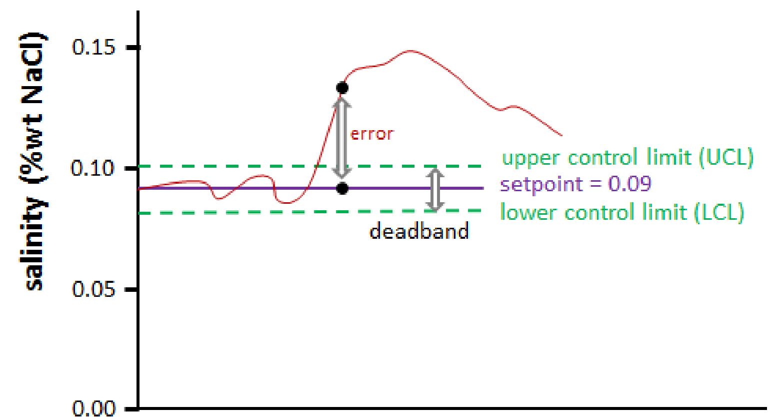
- Compute the UCL, setpoint and LCL values for control of salinity. UCL and LCL depend on the size of the deadband.

- For demonstration purposes, assume that the UCL and LCL are 0.01%NaCl from the setpoint:

$$UCL = 1274.1 \cdot (0.0009 + 0.0001)^{0.1325} = 510$$

$$setpoint = 1274.1 \cdot (0.0009)^{0.1325} = 503$$

$$LCL = 1274.1 \cdot (0.0009 - 0.0001)^{0.1325} = 495$$



- Control strategy:
  - if analogS > UCL (or 510) then open the DI valve an amount proportional to the error
  - If analogS < LCL (or 495), then open the salty valve an amount proportional to the error

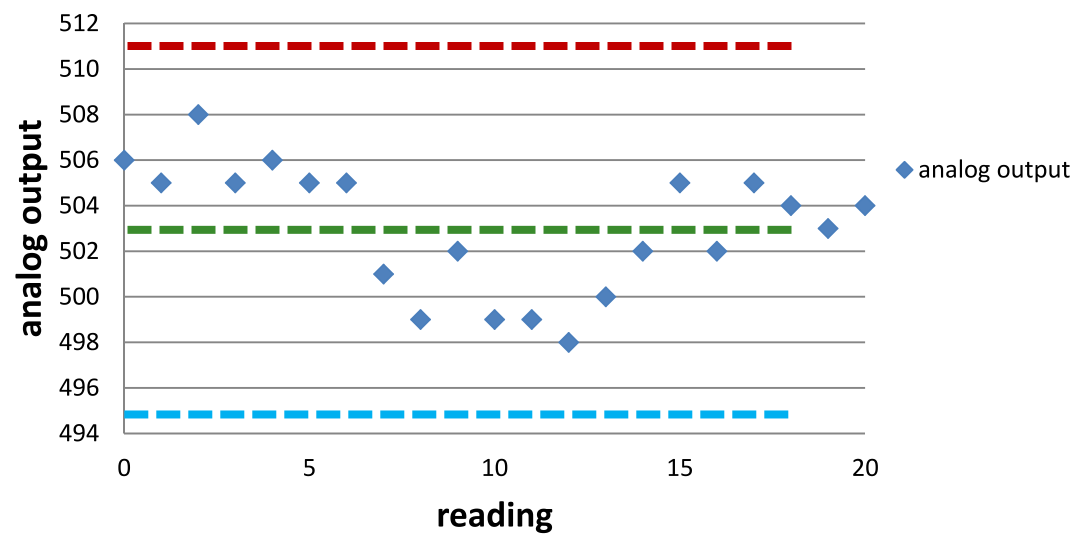
setting UCL and LCL by examining random error

- A better way to determine UCL and LCL are by collecting analogS values for a salinity near the setpoint and then computing the standard deviation (σ) of the "error" of analogS values.
- Using this approach, 99.7% of random error will fall between the LCL and UCL, which means that your solenoid valve will be triggered due to a false alarm only 0.3% of the time.

Example Readings to Illustrate Procedure

reading	analogS
0	506
1	505
2	508
3	505
4	506
5	505
6	505
7	501
8	499
9	502
10	499
11	499
12	498
13	500
14	502
15	505
16	502
17	505
18	504
19	503
20	504

mean=	503
standard deviation=	2.81
3 * standard deviation=	8.43



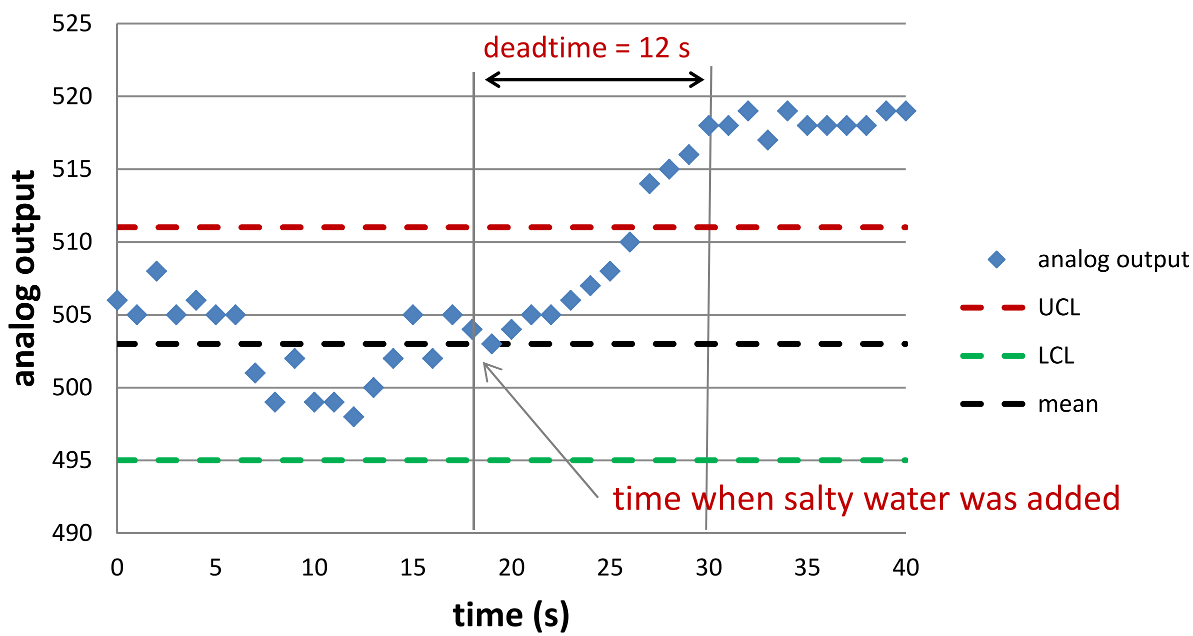
$$setpoint = 1274.1 \cdot (0.0009)^{0.1325} = 503$$

$$UCL = setpoint + 3\sigma = 503 + 8 = 511$$

$$LCL = setpoint - 3\sigma = 503 - 8 = 495$$

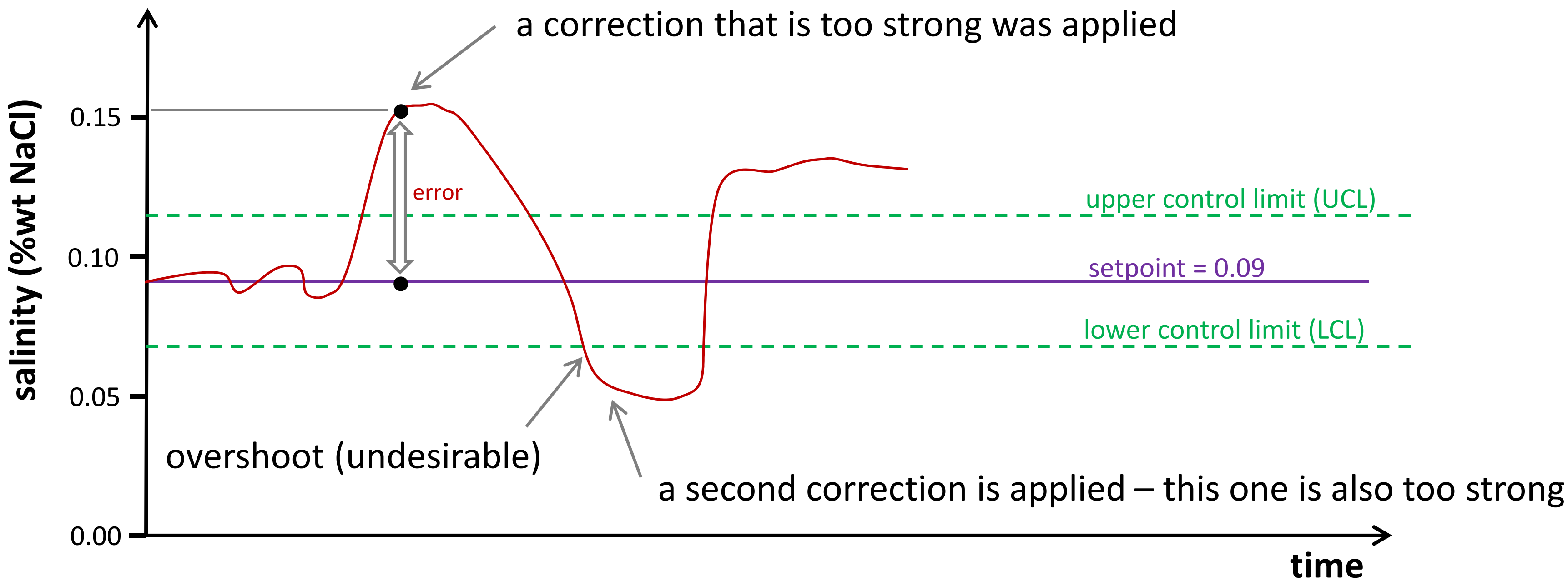
setting deadtime compensation

- It takes time for your system to settle out after the salinity changes.
- Assume the system whose response is depicted in the graph below is “upset” at 18 seconds due to a sudden addition of salty water.
- At about 30 seconds, the salinity values stabilize (with continued random error at the new salinity level).
- For this example, the deadtime compensation would be set to 12 seconds (30s - 18s).
- This means that you would want to allow 12 seconds between salinity corrections.



strength of response to error

- We will compute the amount of salty water that should be added to the current mixture to correct the salinity



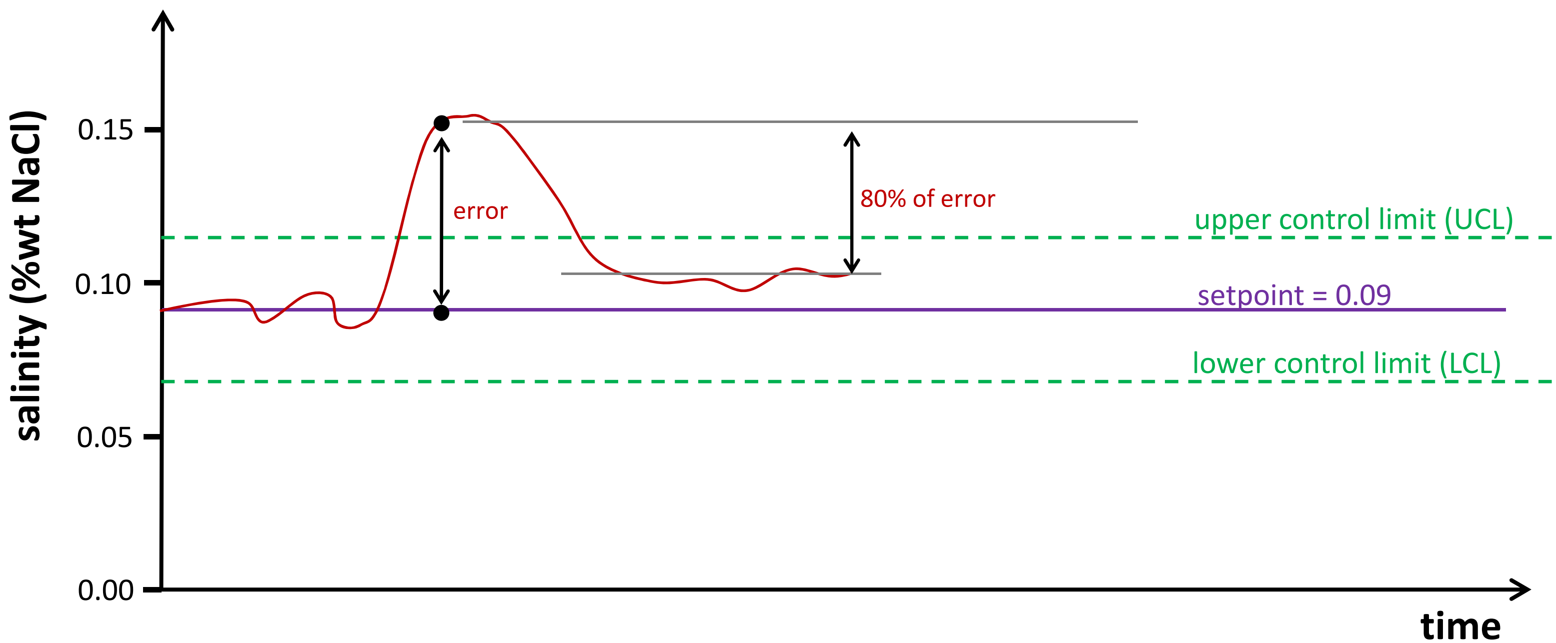
- Over correcting repeatedly causes the system to oscillate about the setpoint

apply a response proportional to error

- We will compute the amount of salty water that should be added to the current mixture to completely correct the salinity
- We will open the solenoid valve long enough to remove a percentage of the error
- For example, if the salinity is 0.152% and the setpoint is 0.09%, then applying an 80% correction will lower the salinity to 0.102%, which is computed as

  correction = (.00152-(.00152-.0009).8)*

- We call the proportionality constant the **gain**; gain is a common term used when working with industrial controllers



teams of 2

Class Problem Assume that your fishtank system has a setpoint of 0.09% NaCl. Your instructor comes by your table and upsets your system by adding a good dose of DI water. The conductivity circuit returns an analog output that corresponds to a salinity of 0.04% NaCl (which is below LCL).

a) What is the target concentration if you have a gain of 0.80 (80%)?
b) Using this gain, how much salty water (1% NaCl) should be added?
c) How long should you leave the valve open if the flow rate is 0.2L/min?

Recommended assumptions:

The water leaves at the overflow is a mixture of water from the salty tank and the fishtank.

The most salty the overflow water can be is 1% NaCl, and the least salty it can be is 0.04% NaCl. Assume that 15% of the overflow water is 1% NaCl and that the rest is 0.04% NaCl.

Neglect density differences between incoming and outgoing water; that is, the mass of water that comes in from the salty tank is equal to the mass of water that leaves through the overflow.

sketch control structure

use your own data

- Compute setpoint, UCL and LCL →

$$setpoint = 1274.1 \cdot (0.0009)^{0.1325} = 503$$
$$UCL = setpoint + 3\sigma = 503 + 8 = 511$$
$$LCL = setpoint - 3\sigma = 503 - 8 = 495$$

- Measure salinity to get analogS (the analog output of the conductivity circuit)
- If analogS > UCL or < LCL & if time since last correction > deadtime then . . .
    - Compute the %wt NaCl →

$$salinity = 3.6686(10)^{-24} \cdot output^{7.5472}$$

use your own data

    - Compute the target salinity based on your gain
    - Compute the time that your salty or DI solenoid valves needs to be left open
    - Open the DI or salty valve for the computed time

to do for salinity control:

- Bring fishtank, water bottles, multimeter & computer to class next time
- Determine flow rate through your solenoid valve (mass per unit time)
- Recalibrate your system
- Determine your fits
  - salinity as a function of analogS
  - analogS as a function of salinity
- Collect data around 0.10% NaCl to determine the standard deviation of the conductivity output so that the UCL and LCL can be determined
- Determine the deadtime compensation (system response time)
- Write your control sketch

THE END ☺