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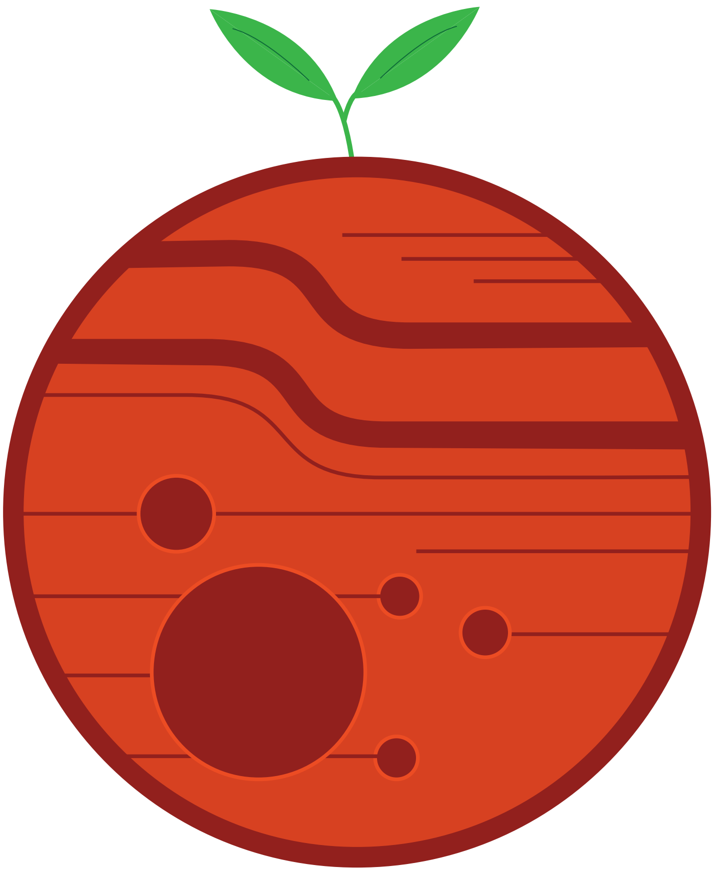
teach with space

→ PLANTS ON MARS

Build an automatic plant watering system



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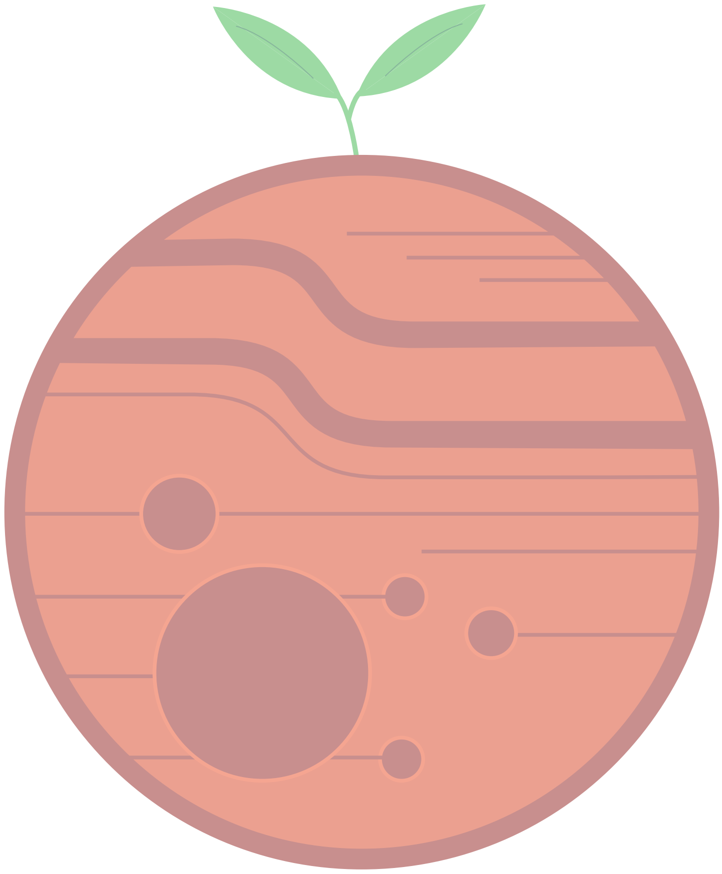

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→ PLANTS ON MARS

Build an automatic plant watering system

Fast facts

Age range: 14-19 years old
Complexity: Medium
Lesson time required: 3 hours
Location: indoor
Includes use of:

- A computer
- An Arduino
- A breadboard
- Circuit cables (male-male and male-female)
- A micro servo motor
- A humidity sensor
- A bottle
- Blu tack
- Cable ties
- Watering tube and water supply
- A bucket
- A potted plant (or soil)

Outline

Students will explore technology used in space through the Arduino tool. They will build an automatic watering system that measures soil humidity and waters a plant accordingly. The basics of programming in C++ will be introduced using the Arduino Integrated Development Environment (IDE) software.

Students will learn

- To identify electronic components
- To understand the basics of programming in C++
- To use and calibrate sensors to take measurements
- The basics of fluid physics
- To implement technology to solve a problem
- To communicate, discuss and evaluate hypotheses
- To work in teams and share ideas
- To understand and evaluate risks and hazards on Mars
- About natural resources
- About closed loops and self-sustainability
- To create a working design by planning, analysing and refining it

→ Summary of activities

Summary of activities					
	Title	**Description**	**Outcome**	**Requirements**	**Time**
0	Welcome to Mars	Students are introduced to Martian conditions and the consequences for sustaining life.	Students will learn and evaluate the differences between Earth and Mars.	None	15 minutes
1	Preparing the Items and First Design	Students are guided via a set of inquiries to design a plant watering system from an equipment list.	Students will understand the need for an automatic watering system, and plan an initial design.	Previous activities Meet Arduino!	30 minutes
2	Design and Test Your Water Reservoir	Students are introduced to basic fluid physics, to refine and test their design.	Students will analyse how their design affects flow rate, and create an ideal design.	Previous activities	40 minutes
3	Mounting the Servo and Connecting the Water Pipe	Students are guided through programming the servo to control water flow.	Students will have a motorised water pipe system to turn ‘on’ and ‘off’.	Previous activities Meet Arduino!	20 minutes
4	Test the Moisture Sensor	Students are guided to program and test the soil moisture sensor.	Students will have a calibrated moisture sensor.	Previous activities Meet Arduino!	15 minutes
5	Connecting All the Components	Students will combine the previous circuits.	Students will have a complete watering system ready.	Previous activities	15 minutes
6	Program Your System	Students are encouraged to design their C++ program for total automation, using flow charts for computational thinking.	Students will learn the importance of testing their program and iterative design, to have a functional, automatic watering system.	Previous activities Meet Arduino!	30 minutes
7	Ready for Mars?	Students will consider adaptations for using their watering system on Mars, discuss ethical issues, and be introduced to Hydroponics.	Students will be able to apply their knowledge about Mars to their design, and form a justified ethical argument.	Previous activities	15 minutes

→ Activity 0: Welcome to Mars

Introduction

This activity introduces students to the context of a Mars space mission, and the challenges that might be associated with living on Mars. The differences between Earth and Mars and what that means for living things are discussed, and students are asked to think about what is needed to sustain life. Students are encouraged to familiarise themselves with the use of Arduino by following the Meet Arduino! classroom resource, for which you can find the link at the end of this resource.

Background information:

From what we already know about Mars, it would be difficult to imagine the life that has evolved on Earth being able to survive the Martian environment. Despite having an axial tilt close to that of Earth's (25° versus Earth's 23°), providing seasons similar to those we experience on Earth, the lack of oceans to help regulate surface temperature and a thin atmosphere (approximately 1% of the density of Earth's) means that the temperature varies greatly from daytime to nighttime.

Mars' orbit is also much more eccentric (elliptical) than Earth's, meaning at some times of the year it is much closer to the Sun than at other times, compounding the problem of extreme temperature variations. The thin atmosphere and lack of ozone, combined with no protection from a magnetic field, means that the surface of Mars is bombarded with harmful UV radiation and solar winds. Searches for a vital resource, liquid water, on the surface of Mars, have so far been unsuccessful. There are, however, signs of a significant amount of water ice.

To increase problems further, CO_2 makes up approximately 96% of the atmosphere, certainly too high for animals on Earth, and too high for many plants. If we want to grow plants on Mars, we may have to incorporate our modern day technologies and tools in order to create sophisticated, artificial habitats and irrigation systems.

However, there are several positive factors. Firstly, the duration of a Martian day is very close to that of an Earth day, lasting 24 hours and 37 minutes. This means that plant photosynthesis-respiration cycles would remain largely the same. Also, despite being further from the Sun than Earth, Mars still receives sufficient sunlight to allow a plant to photosynthesise. Combined with water that could possibly be extracted from Mars' icy poles, we would have two of the vital components needed to support a plant. This could potentially reduce the amount of materials needed to be carried onboard the spacecraft.

Finally, the 'Godilocks' zone is defined as the habitable zone around the Sun because in this area, the temperature range allows water to exist as a liquid on an orbiting planet. The name comes from the fairy tale of 'Goldilocks and the Three Bears', in which a little girl chooses to eat a bowl of porridge that isn't too hot, nor too cold, but just the right temperature!

Exercise answers

1. **To start thinking about this in more detail, list some of the things plants and other living organisms need in order to survive:**
   The main things that plants and other living organisms need to survive and that students should identify here are:
   - An energy source (food for animals and sunlight for plants)
   - Water
   - Nutrients
   - Oxygen
   - Carbon dioxide (necessary for plants to photosynthesise)

They may also discuss things such as shelter and warmth and safety in their environment. These aspects are all relevant, and can be linked to a more in depth discussion on ecosystems and the environment.

2. **Discuss with your classmates and your teacher what you think the answers are to the following questions about the Earth.**
   - **What causes the seasons on Earth?**
   - **What shape is the orbit of the Earth around the Sun?**
   - **What are the main elements present in the Earth's atmosphere?**
   - **What is the Goldilocks zone and does the Earth lie within it?**

   The questions in this exercise are designed to check that the students already understand some basic characteristics of Earth. They should consolidate their existing knowledge but you could take it as an opportunity to clarify common misunderstandings, particularly the cause of Earth's seasons, using the background information above.

3. **Decide whether the following statements are true or false.**
   Using the background information from above and the results of any discussions from the previous exercise, the students should fill in the table as shown below, and consider the justifications for their answers.

Statements about Mars - Table A1	
Statement	True or False
Mars experiences seasons, just like we do on Earth.	True
The orbit of Mars is a similar shape to Earth's, meaning that the temperature on the surface is fairly constant. **The orbit of Mars is much more eccentric, meaning temperature varies much more than on Earth.**	False
Mars has a thick atmosphere, trapping heat from the Sun. **Mars has a very thin atmosphere, meaning that the temperature drops drastically during night-time.**	False
Mars has no magnetic field, this means that there is less protection from harmful UV radiation and solar winds.	True
We have found liquid water on the surface of Mars. **We have found signs of frozen water near the poles, but no liquid water.**	False
The atmosphere of Mars has a similar composition to Earth's atmosphere. **The Martian atmosphere has a much greater percentage of CO_2 than the Earth's atmosphere, and almost no oxygen.**	False
Plants on Mars would need to adapt to the massively different day and night cycles on Mars. **The Martian day is 24 hours and 37 minutes, so the day and night cycles are very similar to those on Earth.**	False
Mars does not exist inside the 'Goldilocks' (habitable) zone, so it is impossible for liquid water to exist on the surface. **Mars exists just on the edge of the habitable zone, so it is possible for liquid water to exist on its surface.**	False

→ Activity 1: Preparing the items and first design

Introduction

The students are tasked with thinking about how they would design an automatic watering system. They are given a list of supplied materials and knowledge of how each of the components works.

Exercise answer

You should expect a wide range of proposals in this exercise. Whilst there are indeed some ideas that may not be feasible, there are many, many more that could be implemented. The students' design here is likely to not be their final design, and students should not be disheartened if they have to change their plan throughout the activities, as this is part of the process. As a teacher, you should look to see if they have thought about the questions posed, and if their proposal makes sense.

→ Activity 2: Design and test your water reservoir

Introduction

In this activity the students will introduce water into their prototype systems to see how their design behaves. This allows the students to go through an iterative scientific process of designing and building a system.

Exercise

1. **Isolate the velocity of the water that comes out of the reservoir (v_2). What is the main variable that it depends on?**
   After applying the principle of conservation of energy in our system, we get to the Bernoulli equation:

$$p_1+\frac{1}{2}\rho v_1^2+\rho g h_1=p_2+\frac{1}{2}\rho v_2^2+\rho g h_2$$

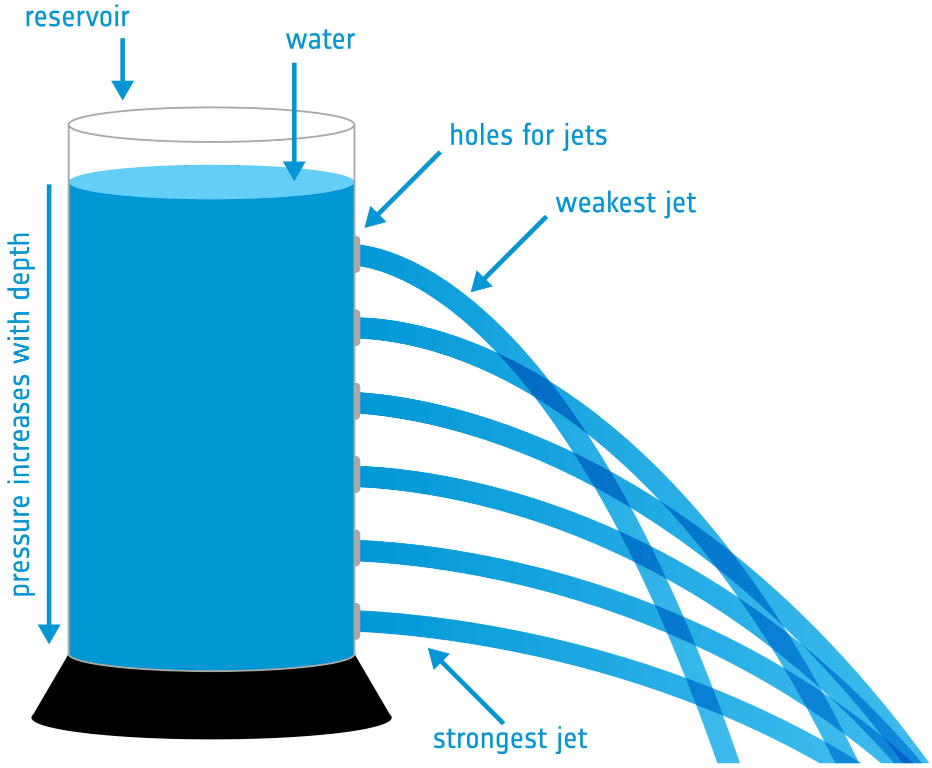
with the first term P being the pressure, the second term ($\frac{1}{2}\rho v^2$) being equivalent to the kinetic energy per unit volume, and the third term ($\rho g h$) the potential energy per unit volume. If we consider a reservoir with a little hole on it (and our flow pipe), we need to consider:

- That both top and bottom are at atmospheric pressure.
- We consider the velocity in the reservoir (v_1) to be approaching 0
- We consider 'height' or cross-section of the flow pipe (h_2) to be approaching 0.

Re-organizing the equation, we have: $p_1-p_2+\rho g(h_1-h_2)=\frac{1}{2}\rho(v_2^2-v_1^2)$

After applying the conditions stated before, it results in: $gh_1=\frac{v_2^2}{2}$

Isolating v_1, we obtain Torricelli's theorem: $v_2=\sqrt{2gh_1}$



2. **After testing your system, which features of your system (the tube and the water bottle) are important when considering how to set up the water reservoir? Specifically, what factors will affect the flow of water and whether it will stop in the 'off' position?**
   Important considerations are:
   - the length of the tube
   - the height of the water bottle
   - the height of the U-bend

   These factors will affect how the water flows in the pipe, and whether or not the flow is stopped in the 'off' position.

3. **Decide if the following statements are true or false:**
   The students are introduced to some aspects of fluid physics. Although it isn't necessary to be familiar and confident manipulating all the equations that are discussed, it is useful to understand their consequences for the plant watering system. This could be done as part of a demonstration to the class.

Statement	True or False
The water will flow more quickly through the tube than in the reservoir	True
The diameter of the bottle is important in determining the flow rate	False
The diameter of the pipe is important in determining the flow rate	True
The height difference between the bottle and the pipe is not important	False

4. **Make use of your new understanding to test the reservoir and then consider how you could refine your design to achieve an ideal setup.**
   The main point to take away from these exercises is that the greater the drop in height between the water bottle and the pipe, the greater the flow of water in the pipe. Students will have to find a balance between the heights they use and the orientation of the pipe in order to build a complete system. For a more precise watering system, students may also want to consider calibrating their system while they test it. This is because the calculated flow velocity is the highest that can be achieved, but the actual flow rate can be slightly lower as the pressure drops in the reservoir. Again, there is no single correct answer here, but you should look for justifications for their chosen design in their sketch.

→ Activity 3: Mounting the servo and connecting the water pipe

Introduction

Now the students are ready to begin the automation of their system. A servo is used to turn the system 'on' and 'off' automatically. You may wish to take an independent direction to the suggested design here, based on the designs proposed by your students.

Exercise

Firstly, the students will connect the servo to the watering pipe and a suitable wall. Students will then make use of the 'sweep' routine, included in the Arduino IDE, to understand how the servo works, and to gain a better understanding of how to incorporate it into their system.

→ Activity 4: Test the moisture sensor

Introduction

In order to fully automate the plant watering system, we have to know when the plant needs watering. So in this activity students are introduced to the soil moisture sensor. The specific instructions required may vary from those given in the guide, depending on the soil moisture sensor you use. Have a look at Annex 1 for more guidance on how moisture sensors can require a different set up or configuration. You should always refer to the data sheet and any supporting material from the manufacturer when building the circuit.

Exercise

If the students have completed the Meet Arduino! classroom resource, then this activity is straightforward. If problems with the code or sensor persist, double check that the connections between the components are correct and that the chosen baud rate is suitable.

The values that the students get for the dry and wet readings will vary from sensor to sensor. The value chosen to switch between 'on' and 'off' should be between the two values.

→ Activity 5: Connecting all the components

Introduction

Now the students are ready to combine all the elements of their system into one complete plant watering system.

Exercise

This exercise requires that the students combine the circuits they built in activities 3 and 4, and so should be straightforward. Again, consult the datasheet of the sensors you use to ensure that the correct ports on the Arduino are chosen.

→ Activity 6: Program your system

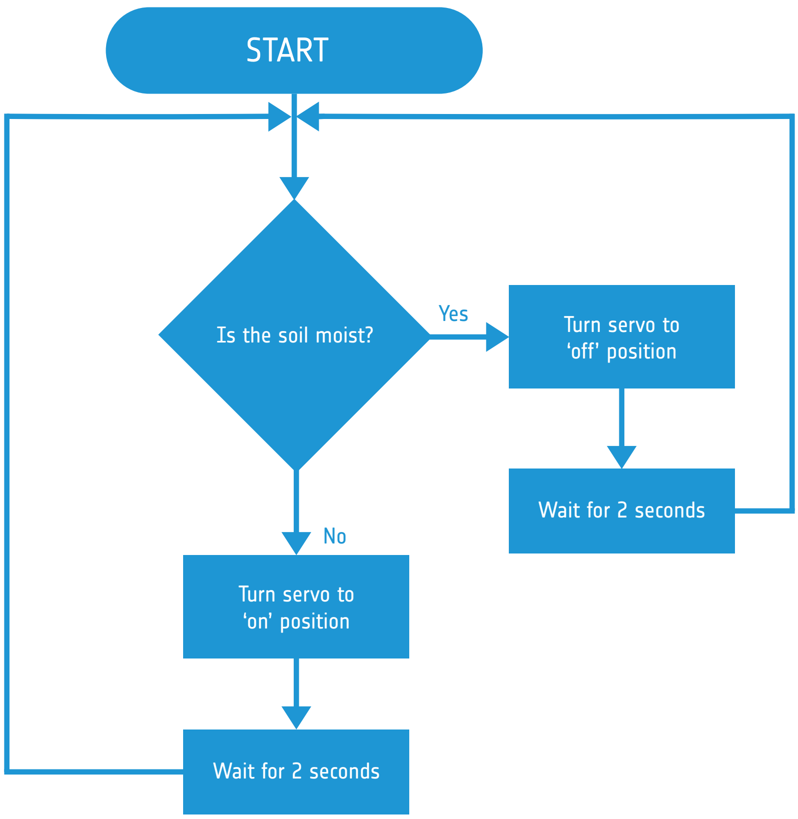
Introduction

Now that the students have their system built, it's time to program the Arduino to operate all the components automatically. The problem is broken down into manageable steps, and students are asked to produce a flow chart before writing any code.

Exercise

1. **Have a go at writing your 'code' in the form of a flow chart below.**
   Although thought processes and the designs of the watering systems your students propose will vary, it is almost certain that they will include the use of an "if, else" statement in their code. The flow chart should therefore make use of a 'decision' box, indicated by a diamond.

   A simple flow chart of what we want our code to do is shown below.



2. **Using the variables we defined earlier, have a go at writing your own "if, else" statement using correct syntax in the space below. You may also want to consider printing the value of the soil moisture in the serial monitor (use the earlier guide if you have forgotten how to do this).**
A completed example is given below. Remember that there are many different ways to approach every problem in programming, so the students shouldn't worry if their code does not match this example exactly, as long as it still compiles!

Figure A13

```
void loop() {
  // put your main code here, to run repeatedly:

soilmoisture = analogRead(soilsensorpin); //reads the soilsensorpin and assignes its value to 'soilmoisture' variable

if (soilmoisture > 600){
  Serial.println();
  Serial.print("Sensor value: "); //for debugging
  Serial.print(soilmoisture);
  waterServo.write(wateringOff);
  delay(2000);
}else
{
  Serial.println();
  Serial.print("Sensor value: "); //for debugging
  Serial.print(soilmoisture);
  waterServo.write(wateringOn);
  delay(2000);
}
```

↑ A completed if, else statement

The "if, else" statement goes in the main loop. The program first reads the value from the soil sensor before using it in the "if, else" statement. In the example above a value of greater than '600' was taken as the soil being sufficiently moist. This value will vary from plant to plant, depending on the plant's needs. The command 'waterServo.write(wateringOn/Off)' is used to turn the servo motor to the required position. Notice the delay at the end of each loop. This ensures that the plant is watered.

3. **Write down any improvements in the space below – could you incorporate it into your code?**
The most obvious improvement to the design of their system would be to incorporate an average reading to take care of any anomaly data. Students may also discuss the benefit of a more robust system than the servo can provide. Again, there are many suggestions that could be made. You should look for the reasoning and justification when judging the validity of each one.

→ Activity 7: Ready for Mars?

Introduction

This activity serves as an introduction to the wider scope of automation and discusses the ethics of such a mission to Mars.

Exercise

1. **Think of the changes that you would have to make to the system if you were on Mars.**
   Many of the resources a plant needs could be monitored in a similar fashion to how we have monitored the moisture levels of the soil. You should check to make sure that the students have covered the resources that they identified in activity 0. In particular, they should address any possible effects of having different amounts of sunlight, potentially harmful radiation, and what the source of water is to continually use the system for a long mission. To advance the discussion further, you could pose the question of whether the reduced gravity on Mars, compared to Earth, would have consequences on the water flow.

2. **Is it ethically sound to send Earth-based life to Mars? What if there is already life on Mars and this is accidentally contaminated or killed?**
   Divide the class into a 'for' group and an 'against' group and ask them to list reasons why we should/ should not perform such a mission. This exercise can be used to create an interesting discussion about the ethics of a manned mission to Mars. Whilst the laws involved are complicated, it can be used to give a context to discussions about space exploration in general.

3. **Can you list some other advantages of Hydroponics for a Mars mission?**
   This activity explores the application of Hydroponics: using nutrient solutions in a water reservoir instead of soil. Make sure the students understand that 'solution' here refers to a substance dissolved in a solvent, a simple example being salt dissolved in water. Some advantages of Hydroponics include:

   - No soil is needed, reducing the amount of materials needed to be carried onboard the spacecraft.
   - Maintaining crops would be less time-consuming.
   - Less water is actually required so the system makes use of resources more efficiently.

→ PLANTS ON MARS

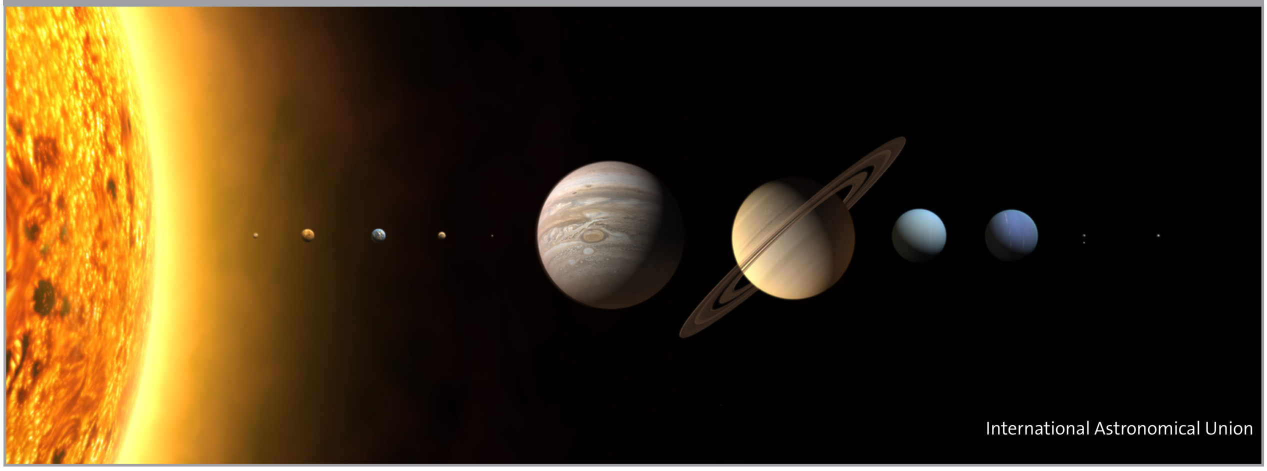
Build an automatic plant watering system

→ Activity 0: Welcome to Mars

Introduction

Mars is the fourth planet from the Sun and the Earth's second closest neighbour, after Venus. The minimum distance between Earth and Mars is a huge 55 million kilometres, compared to the relatively short 380,000 kilometres between the Earth and the Moon. The maximum distance between the Earth and Mars is about 400 million km. Such a big variation in the distance increases the complexity of any missions to Mars significantly, as it is much costlier and more difficult to send supplies.

Figure A1

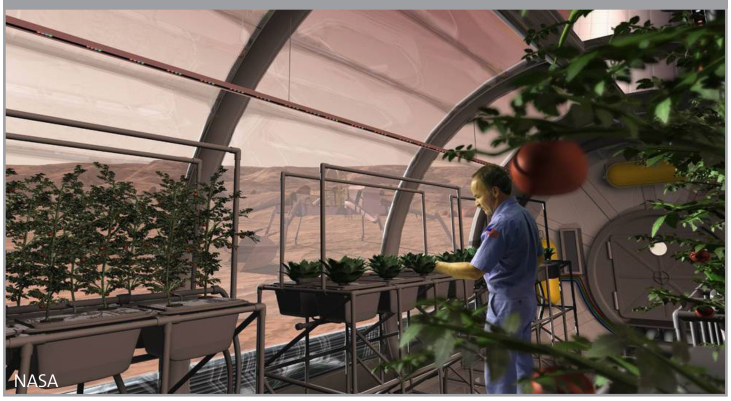


↑ The solar system

A possible solution to this is for the astronauts to take plant seeds with them. This would allow the astronauts to grow the seeds once they arrive, and create a self-sufficient food source.

However, this is not an easy task. There are multiple factors that create a hazardous environment for plants on Mars.

Figure A2



↑ An artist's impression of how a greenhouse on Mars might look.

Exercise

1. To start thinking about this in more detail, list some of the things plants and other living organisms need in order to survive:

2. Before we consider the conditions on Mars, let's check what you understand about the Earth. Discuss with your classmates and your teacher what you think the answers are to the following questions about the Earth:
   - What causes the seasons on Earth?
   - What shape is the orbit of the Earth around the Sun?
   - What are the main elements present in the Earth's atmosphere?
   - What is the Goldilocks zone and does the Earth lie within it?

3. Decide whether the following statements are true or false.

Statements about Mars - Table A1

Statement	True or False
Mars experiences seasons, just like we do on Earth.	
The orbit of Mars is a similar shape to Earth’s, meaning that the temperature on the surface is fairly constant.	
Mars has a thick atmosphere, trapping heat from the Sun.	
Mars has no magnetic field, this means that there is less protection from harmful UV radiation and solar winds.	
We have found liquid water on the surface of Mars.	
The atmosphere of Mars has a similar composition to Earth’s atmosphere.	
Plants on Mars would need to adapt to the massively different day and night cycles on Mars.	
Mars does not exist inside the 'Goldilocks' (habitable) zone, so it is impossible for liquid water to exist on the surface.	

In activities 1 to 7, we will act as space explorers that are on a mission to Mars in order to establish a Mars outpost. To increase the chances of success of the mission, we will build an automatic plant watering system. We are going to experiment and design a prototype here on Earth, so that we can later on adapt it to the Martian environment!

Background exercise – Introduction to Arduino

To get to grips with Arduino and the basics of C++, use the resource ‘Meet Arduino!’. There you will be guided through using several sensors to make measurements of the environment and begin to appreciate how an Arduino can be used.

→ Activity 1: Preparing the items and first design

Introduction

In order for a mission to Mars to be successful, the astronauts will need to be as self-sustaining as possible. This includes recycling as much of their resources as possible and growing their own food.

Plants are a valuable resource. Vegetables are a nutrient-dense source of food that can be grown from small seeds and bulbs, limiting the amount of material that is carried onboard the spacecraft. Photosynthesis, a process carried out in plants to produce glucose for growth and respiration, requires carbon dioxide, of which there is an abundance in the Martian atmosphere. However, plants require constant monitoring if they are to produce good crop, especially if their environment is not naturally abundant in the resources they require.

Maintaining an ecosystem on Mars could therefore require many hours and take up much of the astronauts' time. Our task is to begin to develop a system which would allow a computer to remotely monitor the welfare of a plant and make decisions accordingly. This would give the astronauts more freedom to perform other tasks.

Exercise

Draw a sketch of an automatic watering system, but before think about:

- What possible equipment could I use?
- How will the water be transported to the plant?
- How will we decide if the plant needs watering?
- What problems might we face? How can we overcome these?

In the space below draw and label your initial plan for your watering system

We have chosen a specific set of components to develop a possible system. Combined with your knowledge of how the various components work and the kit list below, your task is to devise a system that can be used to automatically water a plant depending on the moisture levels in the soil.

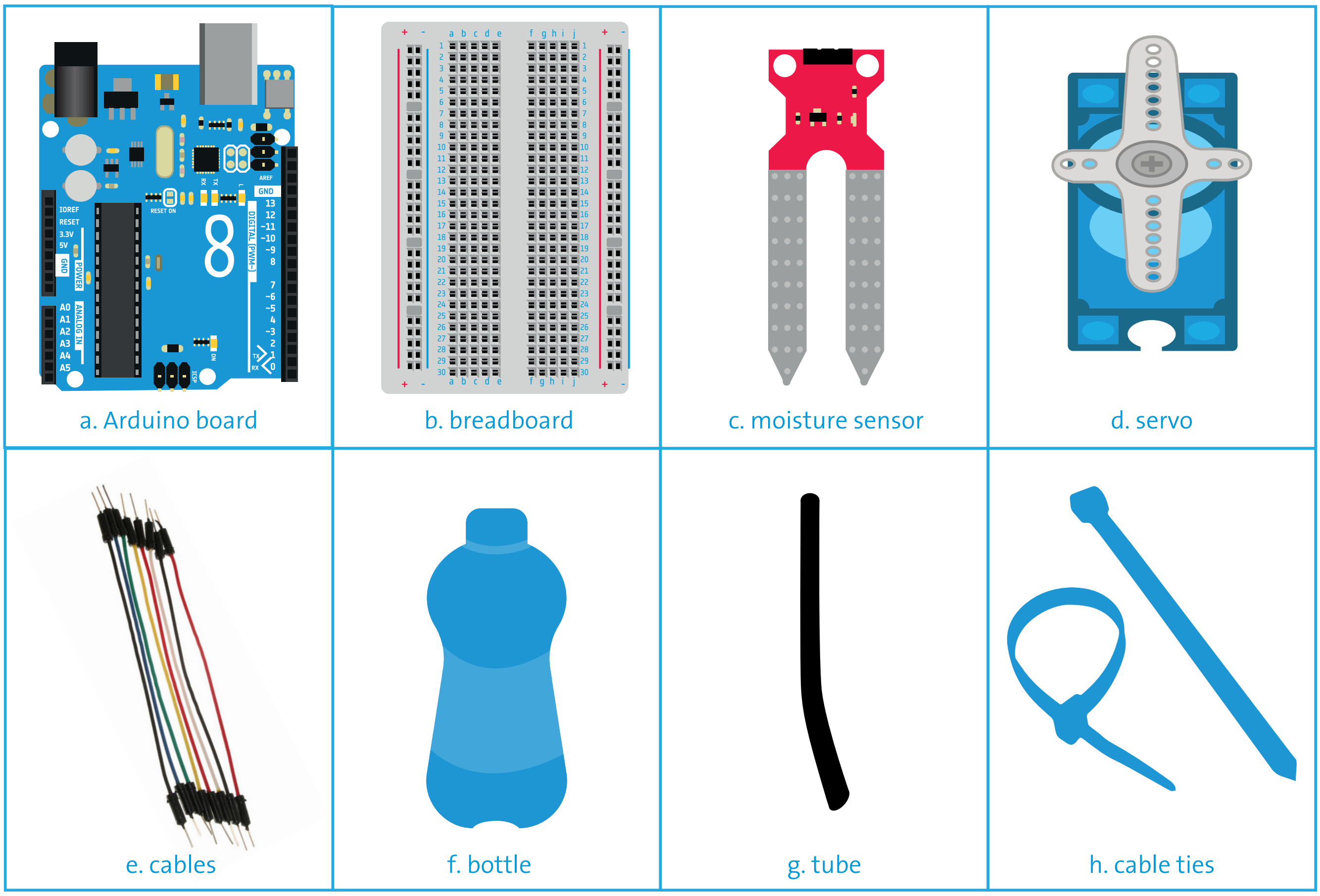
Equipment

- Arduino (such as Arduino Uno)
- Arduino power supply (laptop)
- Soil moisture sensor
- Servo (mini 3-5V is fine)
- Breadboard
- Tube (thin irrigation tube is perfect)
- Soil/plant
- Wires –incl. female-male and male-male
- Scissors/craft knife
- Empty bottle
- Blu-tack/adhesive
- Cable ties
- A bucket

Included in the list above is a servo. A servo is a small motor that, when in a fixed position, can be used to rotate a helix.

First let's think about how the system might physically look – don't worry about the specific electrical connections right now!

Figure A3



↑ Basic components to build an automatic watering system

→ STUDENT WORKSHEET

→ Activity 2: Design and test your water reservoir

Introduction

We now have a basic idea of how our plant watering system could work. The next step is to refine your design through testing! In this exercise you will be guided through constructing a specific design. If your design is different, you will have to adapt the steps, or come up with your own ideas!

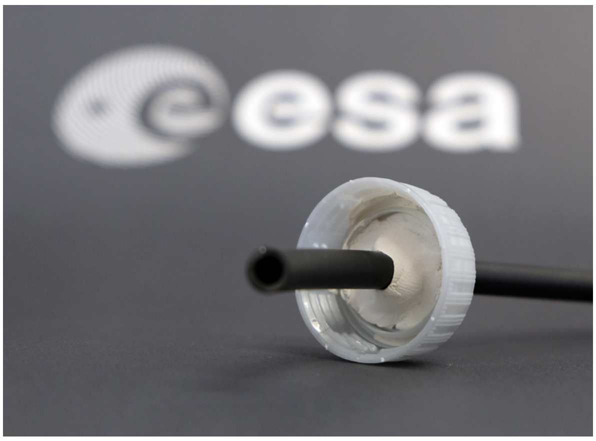
Let's start with the actual design of the system. For this step you will need:

- The water bottle
- Blu tack
- Scissors
- An irrigation tube
- A bucket

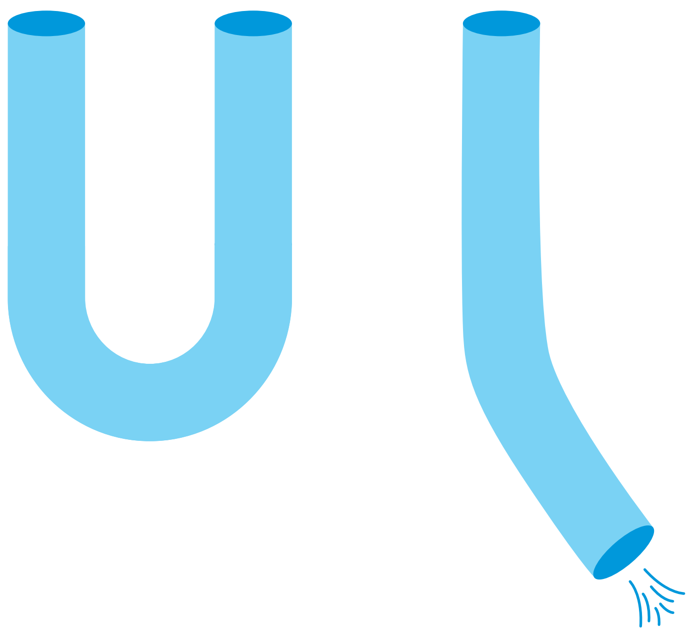
A large, wide bottle makes a perfect reservoir for our watering system. Make sure you keep the lid, and cut off the bottom part of the bottle to be able to keep refilling the reservoir.

Next, we need to create a hole in the cap for our water pipe. A teacher should perform this step! This is best done by slowly and carefully carving a hole to the required size with a pair of scissors. Test with the water tube until you are happy with the fit. The tighter the fit the better. Depending on your workspace, the length of tube you need might vary. But remember – there is no pump in this system so we are relying on gravity to both allow and stop the water flow. Bear this in mind!

Hopefully you were able to create a good fit for the tube, but it is likely that it is not perfectly water tight. This is easily solved with some blu-tack – a glue gun may provide a better seal, if you want to create a more permanent set-up, but it is not necessary for our project.



Now let's start thinking about how our system will work. We need to establish an 'on' and 'off' position – when the tube will be irrigating, and when it won't. An intuitive set-up will be that the end of the tube will be pointing up in the 'off' position and down in the 'on' position. For now, you only need to know that our servo motor will help us in this matter.



Background

Bernoulli equation

Bernoulli's Equation tells us how much the pressure within a moving fluid increases or decreases as the speed of the fluid changes. Here is Bernoulli's equation:

$$p + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

Where:
P is the static pressure in newtons per meter squared
ρ is the density in kilograms per meter squared
v is the velocity in meters per second
g is gravitational acceleration in meters per second squared
h is height in meters

Imagine we make a hole in our water reservoir, in order to plug in our tube. Now let's apply the Bernoulli equation to this system, where the conditions in (1) are the ones in the water reservoir, and the conditions in (2) are the ones in the pipe.

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Exercise

1. Isolate the velocity of the water that comes out of the reservoir (v_2). What is the main variable that it depends on?

Note: Assume that the hole is very small ($h_2 \sim 0$), and the velocity in the reservoir is much slower than in the tube ($v_1 \sim 0$).

2. After testing your system, which features of your system (the tube and the water bottle) are important when considering how to set up the water reservoir? Specifically, what factors will affect the flow of water and whether it will stop in the 'off' position?

3. Decide if the following statements are true or false:

Statement	True or False
The water will flow more quickly through the tube than in the reservoir	
The diameter of the bottle is important in determining the flow rate	
The diameter of the pipe is important in determining the flow rate	
The height difference between the bottle and the pipe is not important	

4. Make use of your new understanding to test the reservoir and then consider how you could refine your design to achieve an ideal setup.

Draw your ideal setup after testing your water reservoir and label it.

→ Activity 3: Mounting the servo and connecting the water pipe

Introduction

We now have a pretty good idea of what our system will look like, but at the moment it requires our input and intervention to make it work. Our aim is to make this system automated, so that astronauts can use their time more effectively. One of the ways we can do this is to make use of a servo.

Exercise

For this activity, you will need:

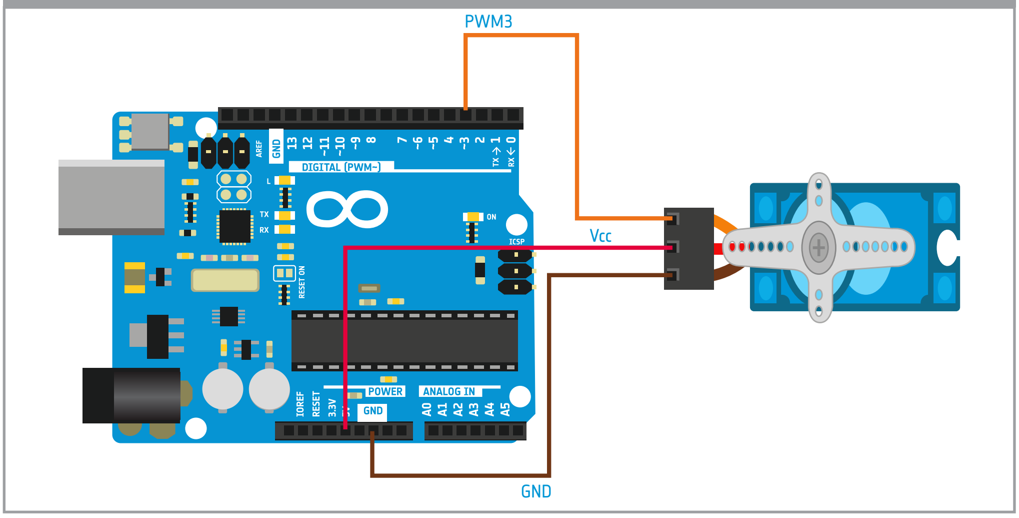
- Your water reservoir
- Blu tack
- A servo
- Cable ties
- Arduino
- Breadboard
- Wires

Step 1: Learn to program your servo motor

For this step you will need:
- A servo motor
- The Arduino
- A breadboard (optional)
- 3 male to male wires

You will need to use the wires to connect your servo to the Arduino Uno. You can either do this directly into the Arduino or plug 3 additional cables into the breadboard.

Figure A4



↑ The setup of the Arduino and servo

The Arduino IDE includes an example sketch named 'sweep'. This can be used to test the stability and the movement of the servo. The orientation can easily be altered by removing and rotating the helix.
To test your servo, write a simple code like the one shown below. This code will rotate the servo by 100 degrees every two seconds.

Figure A5

```
#include <Servo.h>

Servo myservo;  // create servo object to control a servo

void setup() {
  myservo.attach(3);  // attaches the servo on pin 3 to the servo object
}

void loop() {
    myservo.write(100);              // tell servo to go to position in variable 'pos'
    delay(2000);                       // waits 15ms for the servo to reach the position
    myservo.write(0);              // tell servo to go to position in variable 'pos'
    delay(2000);                       // waits 15ms for the servo to reach the position
  }
```

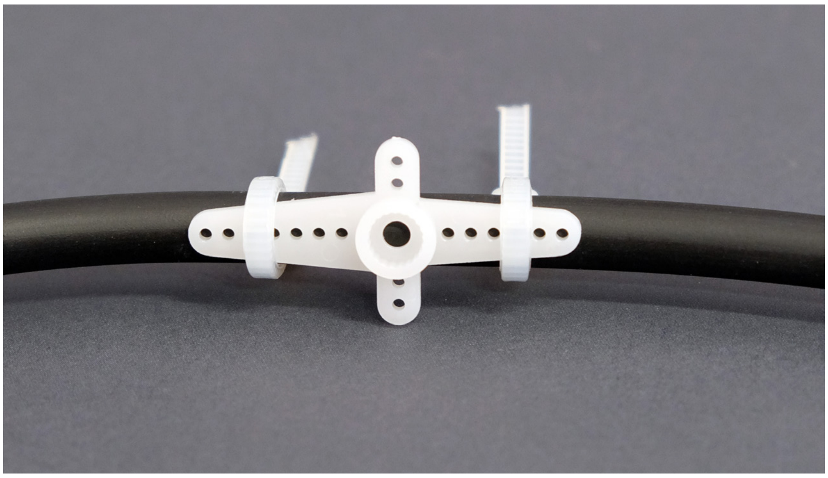
↑ Code to test the servo

Step 2: Motorise your system

For this step, we will need the additional items:

- Blu tack
- Your water reservoir
- A flat, vertical surface to which you can attach the servo
- Cable ties

Now that we know how to program our servo, we can disconnect it from the Arduino so that we can place it in our new setup.



For this, we need to mount our servo and connect it to the water pipe. Blu tack can be used to mount the servo to a suitable wall. Again a glue gun would provide a more permanent fixture but it is likely that you will have to make adjustments to your setup during the early stages.

Included in most servo kits are a set of helixes. We will use one of these to connect the pipe to the servo, using two cable ties to secure it.

The length between the end of the pipe and the helix is important – the bend created by the servo must be sufficiently long to stop the water flow. If the bend is too small, water will continue to flow in the 'off' position – the Martian plants will not survive!

Now we are ready to fix the pipe to the servo. Simply click into place and we're almost ready!

Now we will connect our servo to the Arduino in order to establish whether or not the water can be stopped with our current set-up. Once the setup is complete you are ready to test.

Health & safety!

Before you begin make sure that:

- You have a bucket to collect any water
- Electronics and wires are a safe distance from the water bottle and any potential spillage

When finding the ideal location for your servo you will have to find the right balance between:

- The height of the water bottle
- The height of the servo
- The position of the helix on the pipe
- The orientation of the helix on the servo
- The degrees of rotation used in the code between the 'on' and 'off' position

Make a note of any adjustment you made to your system as a result of your testing:

→ Activity 4: Test the moisture sensor

Introduction

Now that we have the first half of our system working, it is time to test the soil moisture sensor and see how we will incorporate it into our system. The two 'legs' of the moisture sensor work as a variable resistor. The more water in the soil, the better the conductivity, and vice versa. We will use this principle in order to completely automate our system.

Exercise

For this activity, you will need:

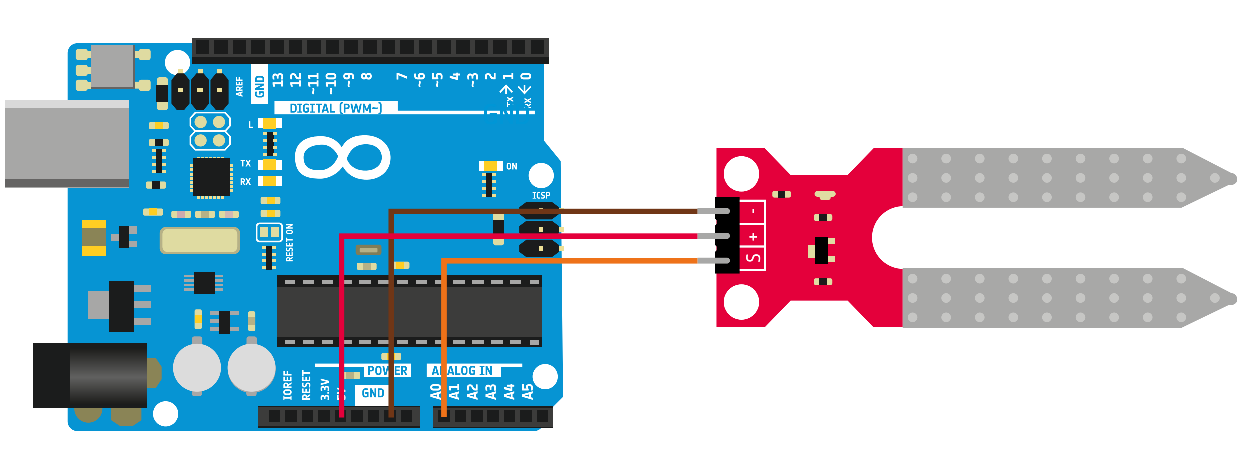
- Soil moisture sensor
- Male-Female wires
- Breadboard
- Arduino

Note:

Some sensors are calibrated to give a higher reading at higher conductivity, whereas others give a lower reading. To understand which sensor you have, compare a reading in the air to one in the water – do not fully submerge the sensor!

To test your moisture sensor, connect it to your Arduino as shown in the diagram.

Figure A7



↑ The configuration for a soil moisture sensor without an external controller board

We are now ready to write a simple code to measure and display the value of the moisture sensor.

The code in Figure A8 takes a reading every second and prints the value in the serial monitor. Use this code to test your moisture sensor and to calibrate your watering system.

Figure A8

```
int soilsensorpin = 0;
int soilmoisture;

void setup() {
Serial.begin(9600);    //baudrate serial monitor

}

void loop() {
soilmoisture = analogRead(soilsensorpin);

Serial.println();
Serial.print("sensor value = ");
Serial.print(soilmoisture);
delay(2000);

}
```

↑ Code to calibrate the moisture sensor

Exercise

- What value does the sensor give when placed in water? ______________________
- What value does the sensor give in 'dry' air? ______________________
- What would be a suitable value to switch your system from 'on' to 'off'?

____

Once you are happy with how the sensor works, you are ready to complete the setup!

→ Activity 5: Connecting all the components

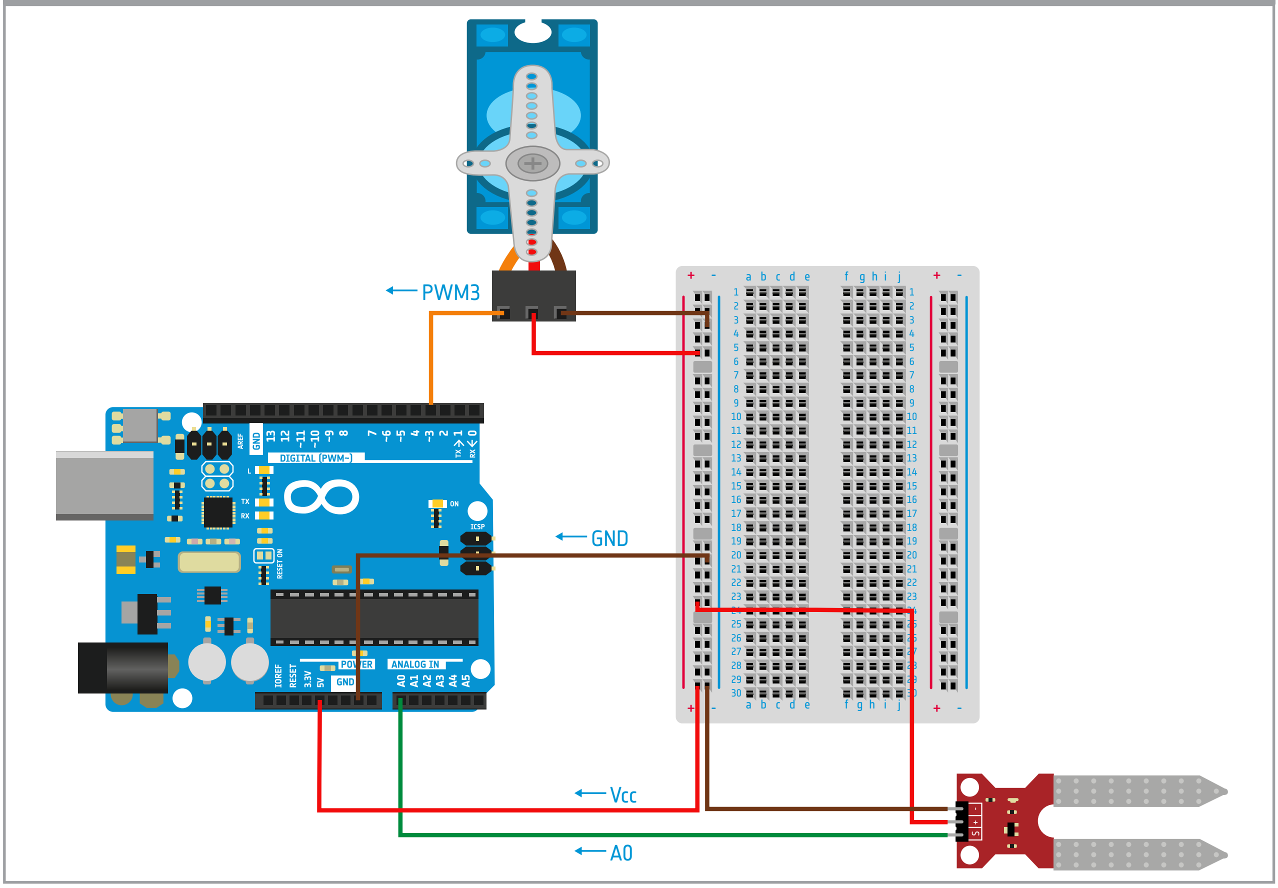
Introduction

Almost there! We now have a good understanding of all the elements of our system. Now it is time to put them all together and test the system to see if it all works.

Exercise

Once you are happy with each element of your water system you are ready to complete the setup by connecting the components to the Arduino. After following the earlier guides this should be straightforward. A diagram of the entire setup is shown below. Take care! Depending on the moisture sensor you use, the arrangement of the pins may differ. Always refer to the manufacturer's data sheet if you have any concerns.

Figure A9



↑ Electrical connections between the Arduino, servo, and soil moisture sensor

The wires on the servo are colour coded as follows: brown – ground (GND), red – 5V (Vcc), orange – 'pulse'. Take note of the four digital pins on the Arduino board that have ~ next to their number (3, 9, 10 and 11). This symbol denotes that the pin is a pulse-width modulation pin. If you're interested in what this means, more information can be found at: https://learn.sparkfun.com/tutorials/pulse-width-modulation. It is important to us as this is the type of pin required by the servo.

→ Activity 6: Program your system

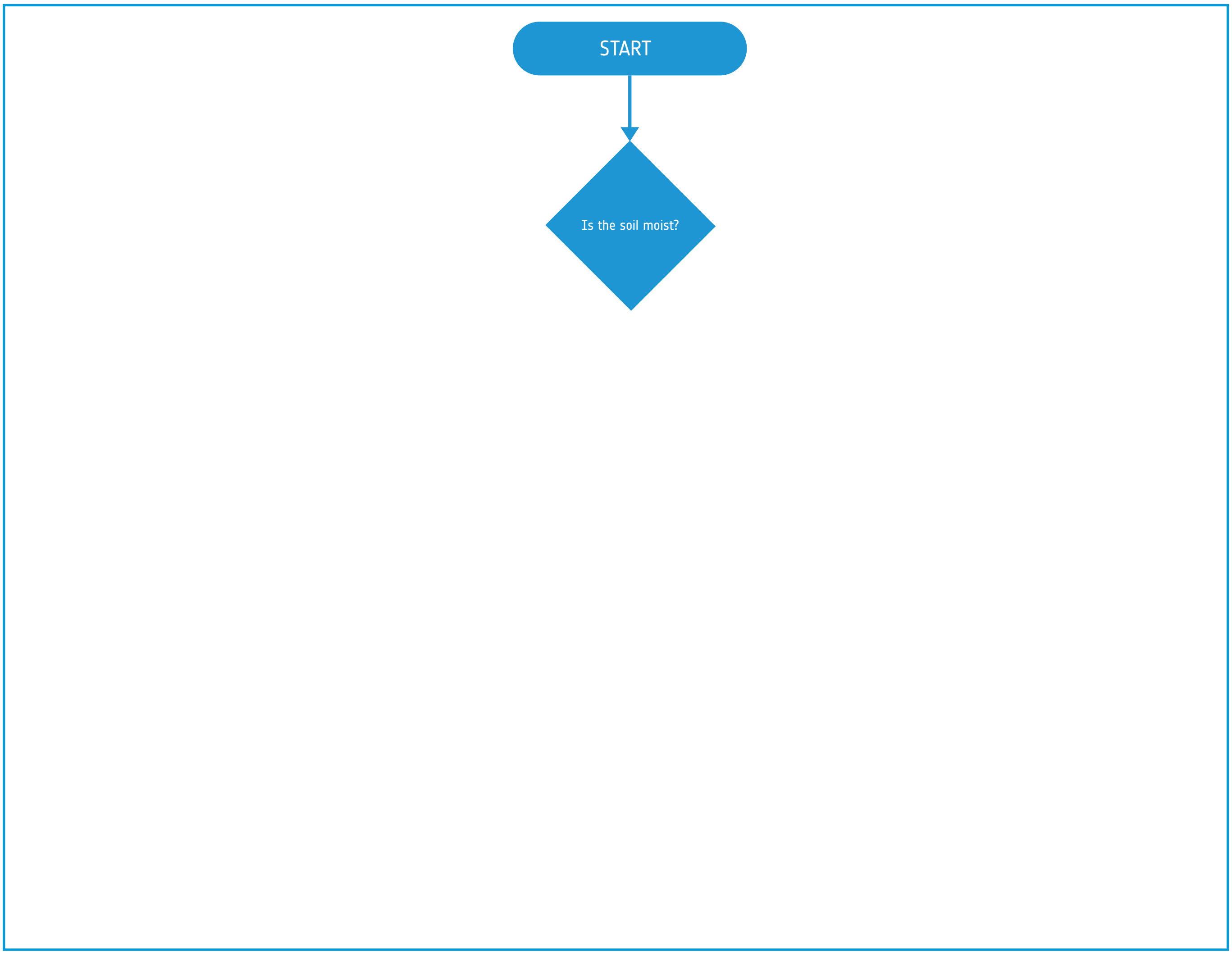
Introduction

We have tested each element of the system separately, both mechanically and using code. In the previous activity we assembled the system. Now it's time to write the single code that will be used to run the entire system! It is not as daunting as it sounds. We have already done most of the work, it's just time to put it all together.

Exercise

To make writing our code easier, we can think through the problem on paper first, using the same logic that you will use when you come to write the code. This is easily done in a flow chart. Typically, a rectangle in a flow chart is a command, and a diamond is a question/decision. Arrows are used to show the path through the chart, depending on the decisions made.

1. Have a go at writing your 'code' in the form of a flow chart below:



We now have everything in place to start running our automated plant watering system. All that is left is to write the code and send it to our Arduino.

The first thing we must do in our code is establish several quantities/variables including: the pin used for the soil sensor, the pin used for the servo, a variable to store the sensor reading, and both an on and off position for the servo. All of this is done via the 'int' command. We must also define a name for our servo and ensure that the Servo library is called into the code.

Figure A10

```
#include <Servo.h>
Servo waterServo;  //creates the name of your servo
int soilsensorpin = 0;  //assignes a pin for the soil sensor
int servoPin = 3; //sets the servo pin, this must be a PWM pin
int soilmoisture;    //variable to store one sensor reading
int wateringOn = 0; //position of servo to allow water to flow
int wateringOff = 120; //position of servo to hold water
```

↑ Establishing variables in our code

Take note, the servo position is given in degrees and the values you will need to use will depend on the orientation of your servo/helix, and will likely be different from the numbers you see above.

Next, as in earlier examples, we must establish a baud rate (closely linked to the bit-rate, the rate at which information/data is transferred). We must also tell the Arduino that the servo is an output.

Figure A11

```
void setup() {

Serial.begin(9600);   //baudrate serial monitor
waterServo.attach(servoPin); //sets servo pin as output
}
```

↑ Setting up the program

Now we are ready to begin writing our main program. We can see, looking at the flow chart, that the Arduino must measure a variable (in this case 'soilmoisture') and do one of two things depending on its value. In C++ this situation can easily be dealt with by using an 'if, else' statement.

The syntax of an 'if, else' is very simple, and can be seen below:

```
if(boolean_expression) {
// statement(s) will execute if the boolean expression is true
} else {
// statement(s) will execute if the boolean expression is false
}
```

A 'boolean expression' is a mathematical statement that is either true or false and often includes the use of the following symbols: <, >, =.

2. Using the variables we defined earlier, have a go at writing your own "if, else" statement using correct syntax in the space below. You may also want to consider printing the value of the soil moisture in the serial monitor (use the earlier guide if you have forgotten how to do this).

```
if(                          ) {




} else
{
```

You are now ready to run your program! It is a good idea to first test without any water in the system – water and electronics do not mix well and the program might not run exactly as you anticipate!

Whilst the code we have designed does what it is supposed to do, there are many ways it could be improved. For example:

3. Write down any improvements in the space below – could you incorporate it into your code?

Did you know?

Annual worldwide water consumption from irrigation is set to break 1500 cubic kilometres by 2025! It is therefore vital that any irrigation systems that are designed for a mission to Mars are as efficient and self-sustaining as possible, otherwise the quantities of water required alone will make the mission unfeasible....

→ Activity 7: Ready for Mars?

Introduction

Water is of course just one of the many vital resources a plant needs to survive. How could the system be developed to be an inclusive, autonomous system capable of monitoring and keeping plants healthy in a Martian environment? Is there anything unique about the environment on Mars that we need to take into account? Are there any other concerns with a mission to Mars? Remember, everything required for the system has to make the journey with the astronauts so simple, lightweight solutions are best!

Exercise

1. Think of the changes that you would have to make to the system if you were on Mars. Consider:
   - Were there any anomaly readings? If so, how could you deal with these?
   - Did the water flow only when it was required?
   - What are the differences between Earth and Mars, and do any of these differences have consequences for our system?

____

____

____

____

____

____

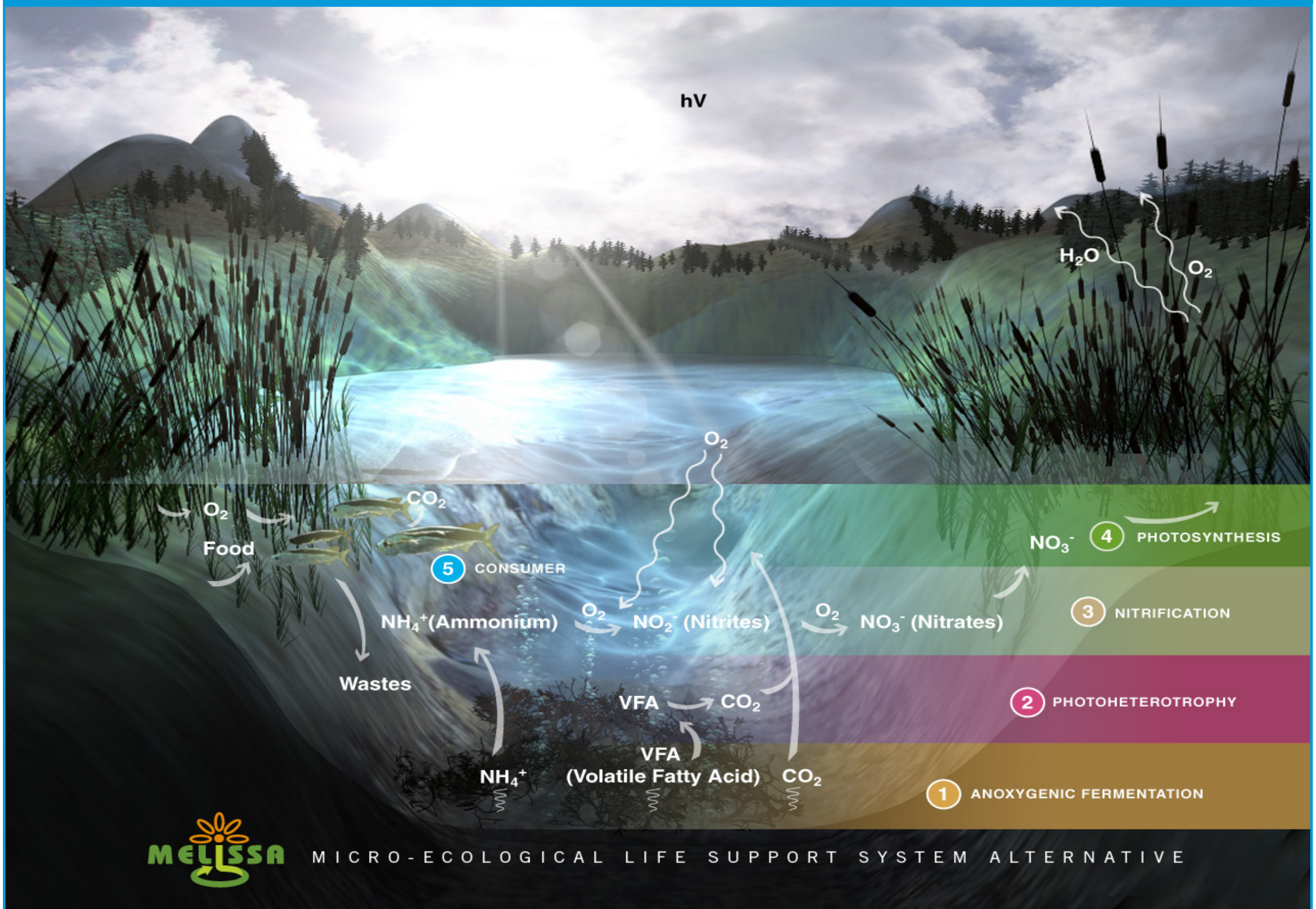
2. Is it ethically sound to send Earth-based life to Mars? What if there is already life on Mars and this is accidentally contaminated or killed?
   Your teacher will assign you to a group to think of arguments either 'for' or 'against' such a Mars mission. Try to debate your reasons with your peers. Some starting points for each side of the argument are given below.

For	Against
• We need to do it for humanity to survive • It could teach us about life on Earth • It could be contained • ...... •	• We could contaminate or kill already existing life • Radiation could result in unpredictable mutations in life • ...... • ......

One aspect that you may not have considered yet is how will the plants receive enough nutrients to be healthy? On Earth, we often grow plants in soil, which acts as a reservoir that contains the essential minerals and nutrients that plants need. However, the soil itself isn't actually necessary! Plant roots absorb the nutrients from the soil after they dissolve in water. Hydroponics is a method of growing plants without soil and instead uses water as the reservoir of nutrient solutions. It's a more efficient method because it eliminates water loss due to evaporation and the water is recycled. A crucial advantage for applying this to a Mars mission is that we wouldn't need large amounts of farmland, we would simply need contained greenhouses.

3. Can you list some other advantages of Hydroponics for a Mars mission?

Did you know?



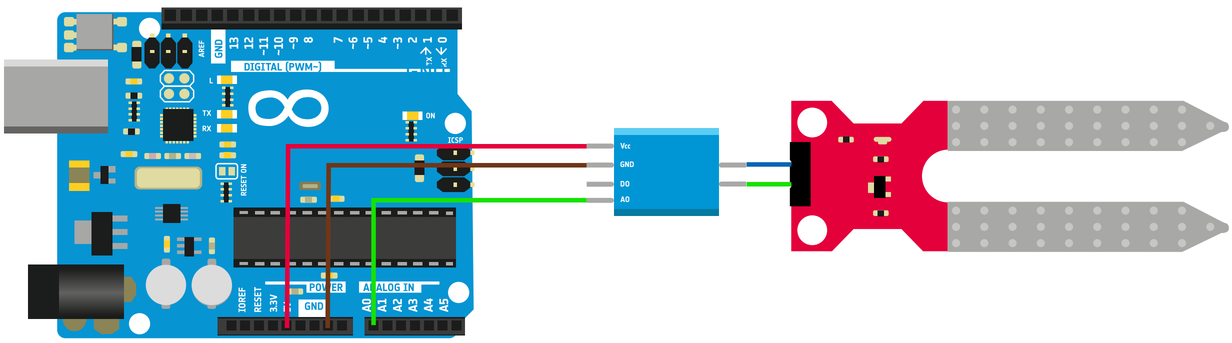
ESA's MELiSSA initiative is the Micro-Ecological Life Support System Alternative, which aims to develop technology for a closed life support system to use in space exploration. It's designed to recreate an artificial ecosystem, similar to a lake on Earth, in which waste products are processed by plants and algae to regenerate food, oxygen and purify water.

➔ Annex 1: Differences between moisture sensors

The moisture sensor discussed in the activities contained an onboard controller and can be connected directly to the pins of the Arduino. Some moisture sensors have an external controller board and must first be connected to this external board before it can interface with the Arduino.

The exact setup will vary between moisture sensors. However, often the pins will be labelled Vcc, GND, AO (analog output) and DO (digital output). If this is the case for the sensor you are using, then a suitable circuit diagram is shown in the figure below. If your sensor is different from both of the sensors we have discussed(with onboard or external controllers) then you should look at the manufacturer's manual for further instructions.

Figure A1



↑ The configuration for a moisture sensor with an external controller board.

→ Links

Meet Arduino! Resource
http://esamultimedia.esa.int/docs/edu/T04.1_Meet_Arduino_C.pdf

ESA's MELiSSA project
https://www.esa.int/Our_Activities/Space_Engineering_Technology/Melis

No Pump Automatic Watering System
https://www.instructables.com/id/No-Pump-Automatic-Watering

Soil Moisture Sensor Guide
https://learn.sparkfun.com/tutorials/soil-moisture-sensor-hookup-guide/all