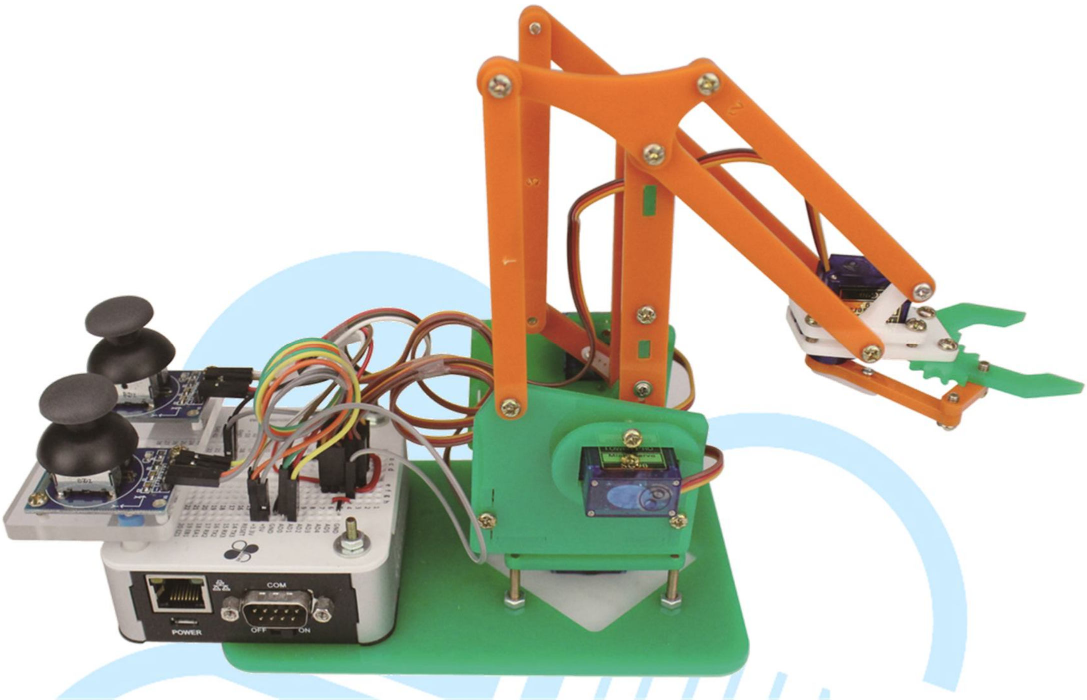
# Control Robotics Arm with EduCake



## 1. About Robotics Arm

Robotics Arm (RobotArm) similar to the one in Figure-1, is used in broad range of industrial automation and manufacturing environment. This type of RobotArm can efficiently replace human to handle assembling and moving heavy object, such as automobile assembly, lifting & moving large and heavy packages. RobotArm can be designed and program to handle heavy objects, that is beyond human's physical ability, and able to replicate these tasks, over and over, with high degree of accuracy which is needed to deliver quality and predictable outcome.

Robotics machinery can help manufacturer in different industries to improve efficiency and quality while minimize cost and safety hazards. Robotics machinery is already an integral part of manufacturing in many industry, such as automotive, food, medical and etc.

Founder for Hon Hai, Terry Gou, talked about the need for "Million Robots Army" for his company's future. Hon Hai is the company that provide manufacturing service to key companies such as Apple.

Figure-1. Robotics Arm from Kuka, http://www.kuka-robotics.com

## 2. Robotics Arm Structure

RobotArm devices for commercial application in industrial-automation and manufacturing are complex and high cost. In addition to the mechanical structure that provides the core function (torch, welding, spray paint, vacuum pickup, magnetic pickup and etc.), there are other motors, servos, hydraulic and electronic components that make up the RobotArm. In order for the RobotArm to function as intended, there are PLC controller, different type of intelligent sensors, computerized monitoring system, alarm system, user interface to interact and operate the system, and other components needed for the system to function. To operate commercial RobotArm efficiently and in a safe manner, workers have to go through training to learn how to use and interact with RobotArm. It's a complex and high cost environment to integrate different components that make up the RobotArm solution for commercial use.

For this application note, we will use a simple implementation to lean basic RobotArm functions, as shown in Figure-2, using a simple mechanical design with low-cost components that can easily be purchased from the DIY/hobbyist marketplace.

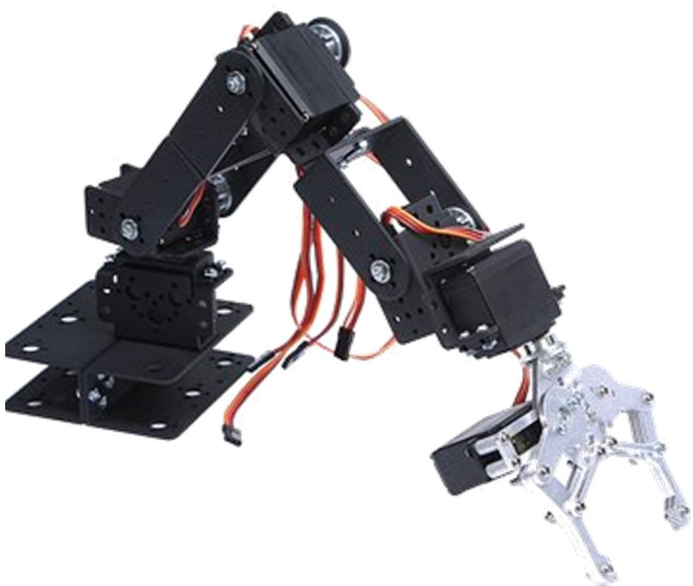


Figure-2. Robotics Arm common in the DIY Hobbyist market

Simple RobotArm design, like the one in Figure-2, has been around for more than 10 years. By controlling movement around different axis, the continuous development in the market created countless derivative from this basic design with different function to serve different objectives. Within the academic community, most of the experiment and teaching contents that involve RobotArm are based on similar design as the one in Figure-2, controlling anywhere from 2 to 10 axis. In recent year, starting around 2013, due to the enhanced communication and access to large pool of shared information, there are significant improvement and new development around RobotArm, especially in the DIY and hobbyist market, such as the uARM which successfully raised over $250K dollars via a Kickstarter project.

https://www.kickstarter.com/projects/ufactory/uarm-put-a-miniature-industrial-robot-arm-on-your

The uARM's success, along with the project's open-source nature which enable others to access the hardware and software design files, triggered multiple similar products with different design, such as playArm, liteArm, meArm, xxArm and etc. We will use meArm for the sample exercise in this application note, as shown in Figure-3.

http://www.thingiverse.com/thing:360108

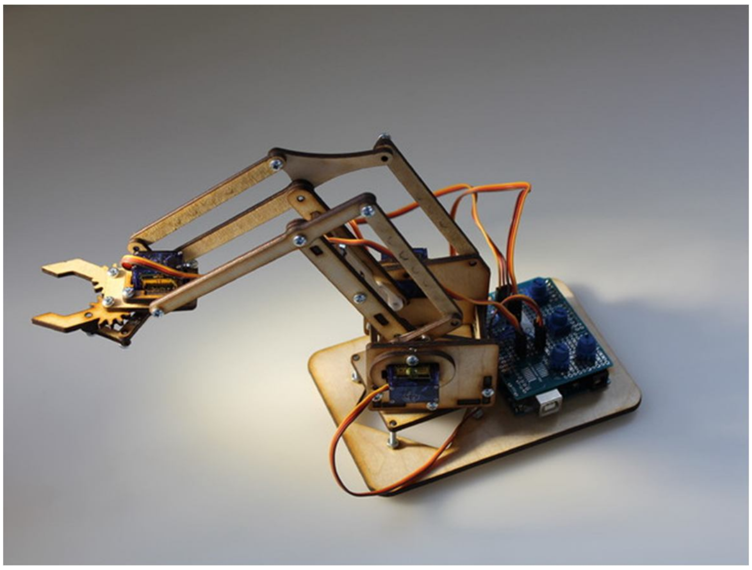


Figure-3. meArm, a popular RobotArm for education in 2014

One of the reason that contribute to the meArm's popularity is the simple design, low-cost, easy to assemble, yet able to replicate and demonstrate commercial RobotArm function and theory in the teaching environment.

# 3. Building the meArm Robotics Arm

The meArm RobotArm consists of the mechanical structure, servo, electronic control circuit, power supply and application code. There are mechanical design files for meArm share by numerous developer where you can use acrylic, aluminum sheet and wood panel, ranging from 2mm to 5mm thickness, and cut out the required parts manually or with help from a laser cutter, as shown in Figure-4.

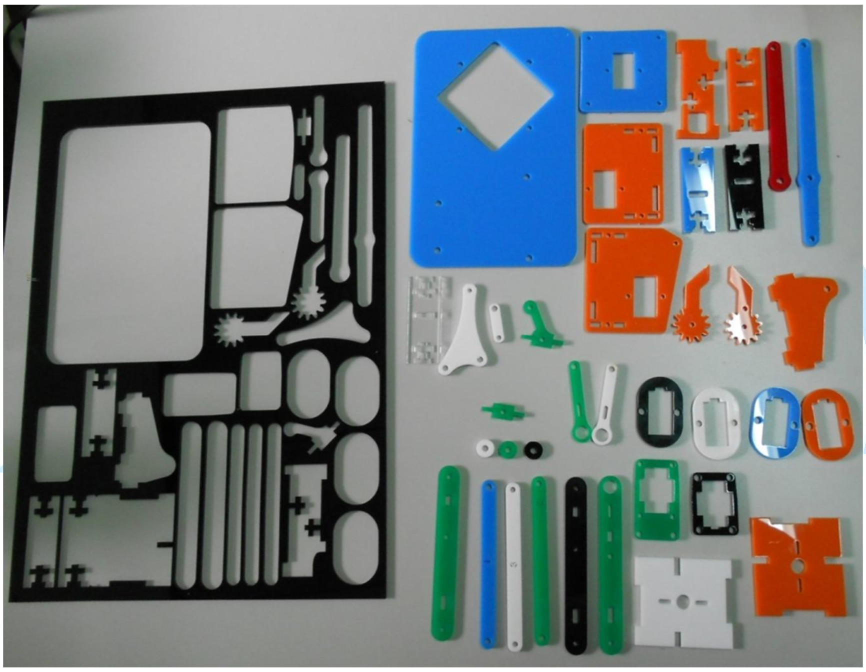


Figure-4. Mechanical component for meArm, laser cut from acrylic panel.

The mechanical parts design in Figure-4 above is based on 3mm panel. When using panel with different thickness, some of the join may not fit well and the length of the screws used to hold different pieces of the panel in place may be different and require adjustment and modification to complete the assembly.

For the exercise in this section, we use a SG90 servo motor. In an earlier application note, PWM Tutorial (Chapter-3), we talked about the SG90 servo along with servo control in great details. Please refer to this application note for additional information not covered here.

Many of the lower cost servo motors are built with larger tolerance in term of the servo's mechanical size, where the servo housing's dimension can vary as much as 1mm, which can be a source of problem in building any robotics devices that require precise mechanical fitting to properly assemble each device for the device to function properly. To correct the mechanical misalignment caused by the variation in the servo's housing, you may need to loosen the mounting bracket to accommodate slightly oversized servo housing or insert a spacer, to fill the space to support servo housings that are slightly smaller.

To provide a lower cost environment to learn about Robotics Arm design, the less precise lower cost SG90 servo is used.

To support Robotics Arm project that requires higher precision, you can use higher cost servo, such as the RS-0263, which can deliver higher torque, faster response, built with metallic gear instead of plastic gear.

http://www.roboard.com/servo_0263.html

The RS-0263 servo can take advantage of the EduCake's 13-bit high precision PWM control signal, which the SG90 servo is not able to.


Figure-5. Low-cost SG90 and high-precision RS-0263 servo

We will use the EduCake as the controller for the exercise in this application note. A joystick module will be used to provide the user interface to control the servo, as shown in Figure-6.

Figure-6. 2 axis Joystick module with push button function.

The joystick module is fairly straight forward to use. It has a 5 pin interface, as following:

1. Vcc (5V)

2. GND (Ground)

3. X-axis movement (analog signal)

4. Y-axis movement (analog signal)

5. Push button control

Analog signal from the X and Y axis are used to determine the joystick's X and Y position and use this parameters to control servo movement. Both the X-axis and Y-axis control within the joystick module each has a 10K ohm variable resistor, which enable the module to output analog value within the 0 ~ 1023 range (1024 possible value). To achieve higher resolution, we can use the EduCake's analogReadResolution() function, which can get up to 11-bit resolution, within the 0 ~ 2047 range.

Due to the low-cost components used to build this type of joystick module, along with the low-cost manufacturing/testing process, the center position for the joystick is generally not at the 512 position (1024 divide by 2), and may vary 20% or more from the expected center position, 470 to 600. Calibration to identify the actual center position is needed for the joystick module to function as intended. Assuming the calibrated center position is 500, we need to allocate a range of value within the center position that represent the center between 470 ~ 530 to minimize erratic signals while the joystick is at the center position, where the application code treat the 470 ~ 530 range as the center position.

The push button control is built-in to the joystick control, by pressing on the joystick to momentary activate the push button. When pressing the joystick to activate the push button, it's difficult to maintain the joystick's position and cause un-intended movement and change the joystick position. For application with sensitive joystick control, it's not a good practice to implement push button as part of the joystick and should design the push button control as a separate mechanical interface.

After the robotics arm is assembled, it should look similar to the one in Figure-7. For information about how to assemble the robotics arm, refer to the information in the online information on the following URL:

https://www.kickstarter.com/projects/ufactory/uarm-put-a-miniature-industrial-robot-arm-on-your

http://blog.ufactory.cc/assembly-diagram-of-uarm/

The Arduino sketch (application code) provided in the above URL can also be used on the EduCake, by changing the code to use the correct I/O pin. In the later section, we will work through sample codes to control the robotics arm

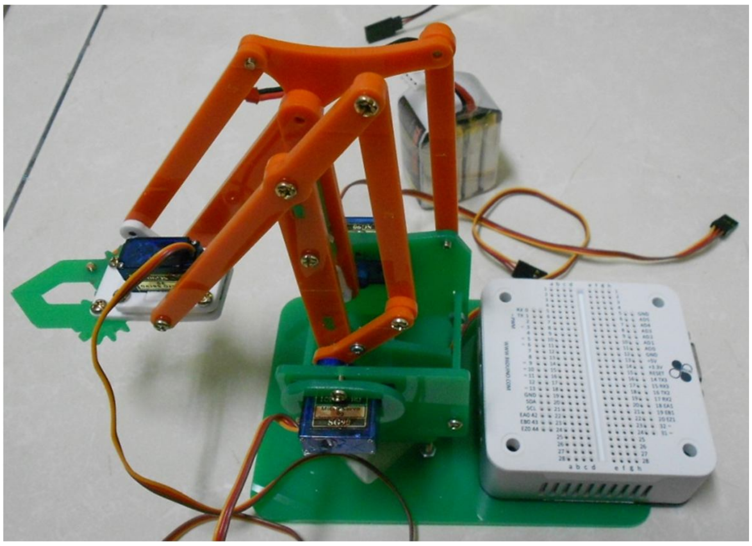


Figure-7 Assembled robotics arm

After the robotics arm is assembled, the servos attached to the base of the robotics arm control the arm move, as shown in Figure-8. The two servos mounted in parallel attaching to different linkage are responsible for extending and retracting the arm while maintaining the jaws' at a certain relative angle needed for the jaws to securely clamping on the object, in order to pick-up the object, which is one of the key design advantage for this type of robotics arm that also help simplify the software needed to control the robotics arm.

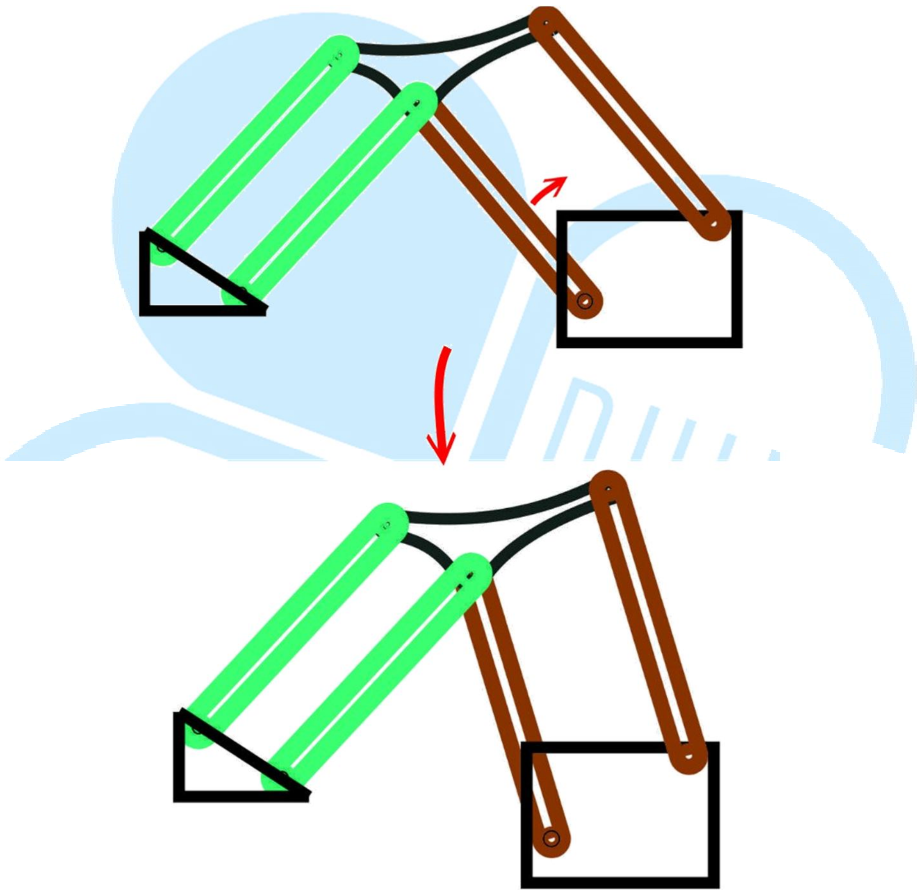


Figure-8 Robotics arm movement driven by servo attached to brown section of the arm.

As shown in Figure-9, the servos attaching to the red-color linkage is used to move the jaws up and down. While it's possible to attach a servo at the mid-section of the robotics arm to move the jaws up and down, adding a servo at the mid-section will add significant weight which can be problematic especially for industrial application where a large size servo with strong torque is needed, where the servo is big and heavy and can shift the center of gravity for the robotics arm to a point where the arm become off balance and tip over. By placing the servo near the base and uses mechanical linkage and join to control the arm and jaws movement, the additional weight from the big and heavy servo help provide additional weight to keep the robotics arm from tipping over when the arm is extending to reach a object further away.

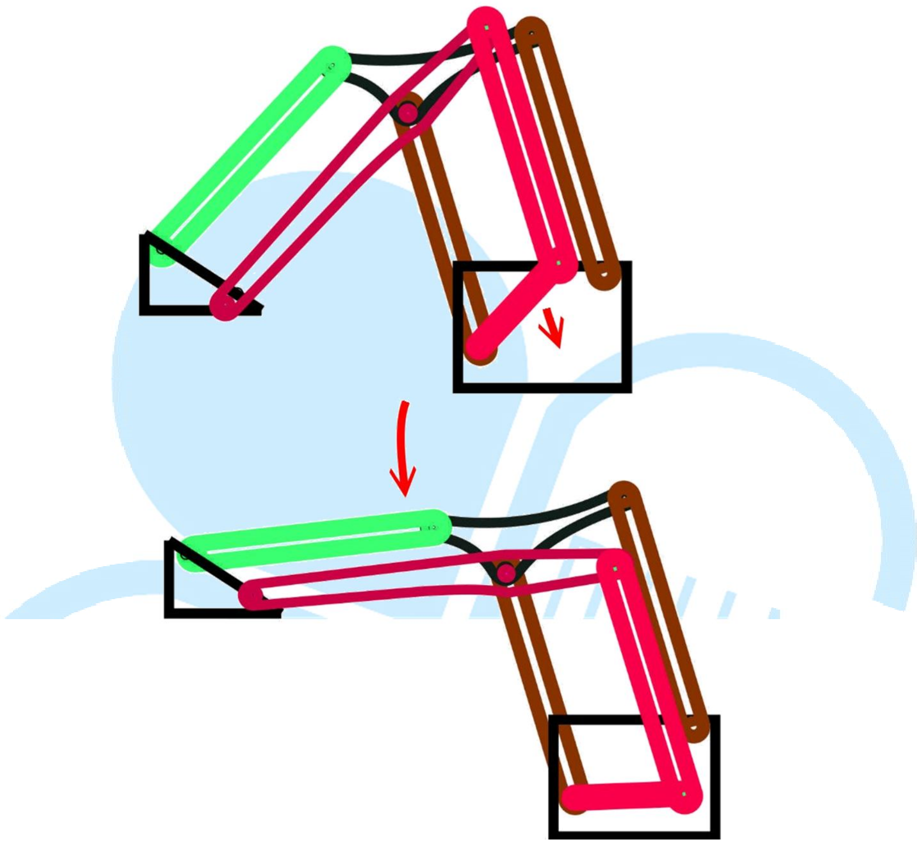


Figure-9 relative robotics arm movement

The drawing in Figure-10 demonstrates the jaws assembly, showing how the servo I attached and its movement to control the jaws' opening and closing via a mechanical gear design as part of the jaws. This type of design can be implemented in smaller size with relatively large opening to grip and hold object.

While it's simple to implement this type of jaws, it has a number of design flaws. Due to the mechanical design, the way the mechanical linkage and servo are attached, the jaws has a range of free and unpredictable movement that cannot be controlled. After the jaws grip and pickup an object, you can feel the jaws assembly is loose and have some movement around the joint. The linkage that attach the servo to control the jaws is too long, where a slight movement by the servo can cause the jaws to open or close by a large ratio, making it difficult to have accurate control over the jaws' movement. A 20 degree movement by the servo' control link can cause the jaws from the close to fully open and vice versa from the fully open to close position. When using the jaws to grip and hold an object, avoid over power and minimize the gripping time which cause high current to flow through the servo. Prolong gripping for long period of time along with over power can damage the servo.

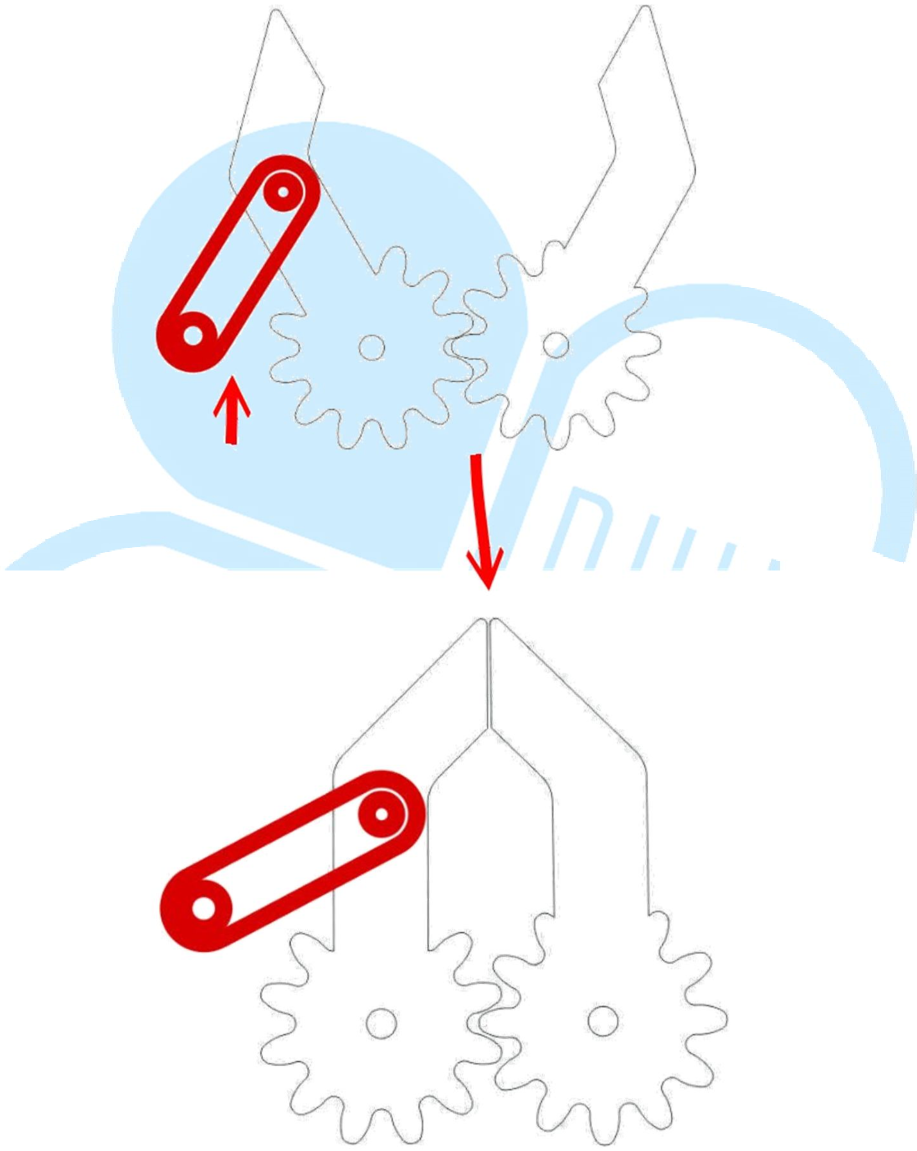


Figure-10. Jaws assembly

The Figures in the previous section provide overview information about the Robotics Arm. When assembling your own unit, it's important to check all the connecting join to make sure all the parts are properly assembled and the arm can move around as intended.

# 4. Robotics Arm Control

In the previous section, we talked about the robotics arm's structure and assembling the robotics arm using a common design with 4 servos, based on the meArm. Since the SG90 servo has limited movement, approximately 80 degree or less in each direction, as shown in Figure-11, one of the area that need particular attention is to align and position each servo to yield maximum control over the robotics arm's movement as the servo move. In addition, you need to check and make sure the robotics arm's mechanical join and assembly can move freely without interference caused by components that are improperly assembled or misaligned components that cause fiction and block the other components' movement.

When working with a new robotics arm design, it's a good practice to check and validate the servo is able to control the robotics arm's as expected, by using a simple PWM circuitry (refer to the PWM application note for more information) to send a 1.5 ms pulse that put the servo's control arm to the center position, a 2.0 ms pulse to turn the servo's control arm to the right most position and a 1.0 ms pulse to turn the servo's control arm to the left most position.

Due to the meArm's simple design, the robotics arm's actual movement and position will be affected by gravity caused by the arm's weight, as it extend and retract, which can be tricky to control. A well designed robotics arm would take these factor as part of the design consideration to achieve more accurate control.

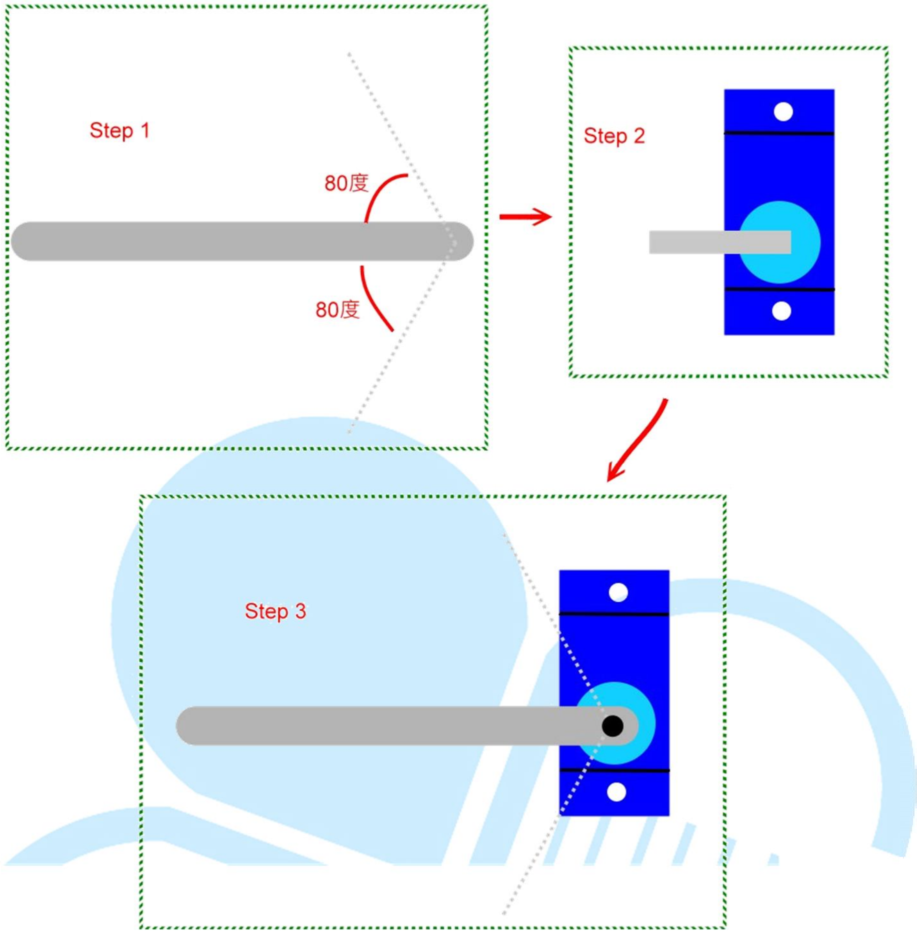



Figure-11. Servo control arm movement

Following is a listing of codes to place the servo's control arm to the center position:

```
#include <Servo.h>
Servo myservo;
void setup()
{
  myservo.attach(3);  // attach servo control to pin #3
}
void loop()
{
  myservo.write(90); // move the servo to the center, 90 degree

  // Calling the writeMicroseconds() to send 1500us pulse as
  // as follow also move the servo to the center position.
  // writeMicroseconds(1500);
}
```

In addition to setting the servo control to the center position, it's a good practice to create additional testing code to gradually move the servo control arm toward the left-most and right-most position to test the robotics arm's movement, to check and make sure these movements do not cause problem. To accomplish this type of testing, you can implement a variable resistor (VR) as part of the circuit where the VR's resistance value is relative to the servo control arm's position, which is also relative to the VR control knob's position. Following is a code listing to control the servo's movement based on the VR's value:

```
#include <Servo.h>
Servo myservo;
void setup()
{
  myservo.attach(3);  // attach servo control to pin #3
 Serial.begin(9600);
}
void loop()
{
   int a;
  a=analogRead(0); // attach VR to analog 0

  // map the VR resistance range to the servo movement,
0 to 180 degree
  a=map(a,0,1023,0,180);

  // Attention: Prior to power on, move the VR control
knob to the center position
  // If the VR is at the lowest or highest position when
power on,
  // it causes the servo to move to immediately move to
the left-most or righ-most position,
  // which can damage the robotics arm, when the
mechanical assembly is not aligned.

  // Move the servo to the position relative to the VR
value
  myservo.write(a);

  // To place the servo in the center position, 90 degree,
  // you can use the following function
  // writeMicroseconds(1500);

  Serial.println(a); // Output current position value to
the serial monitor
}
```

The completed robotics arm assembly, along with the control circuit attached to the EduCake, is shown in Figure-12. One of the servo, at the bottom, is used to rotate the whole robotics arm assembly. Servo #1 is used to control the rear arm's movement. Servo #2 is used to control the forearm movement and Servo #3 is used to control the jaws.

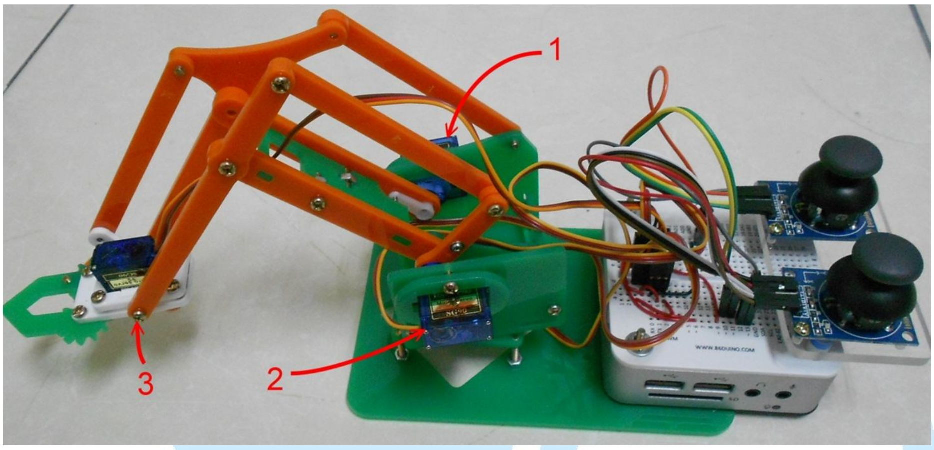



Figure-12 . Completed robotics arm assembly

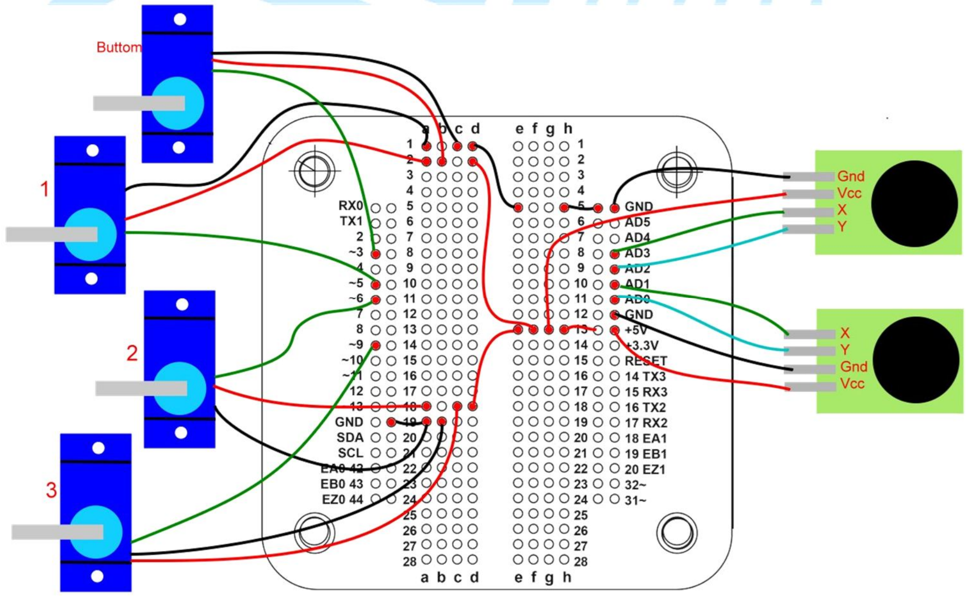



Figure-13. Control circuit attached to EduCake

As shown in Figure-13, the 4 servo motors are attached to digital pin 3, 5, 6 and 9, on the EduCake, which is capable to generate PWM output. The 2 joystick modules are attached to analog pin 0, 1, 2 and 3, and is used to send control signal to control the robotics arm's rotation, extend, retract and jaws movement.

# 5. Controlling the Completed Robotics Arm

The following code listing is to control the completed robotics arm's movement:

```
#include <Servo.h>

Servo myservo1; // Servo to rotate the robotics arm
assembly
Servo myservo2; // Servo to control rear arm movement
Servo myservo3; // Servo to control forearm movement
Servo myservo4; // Servo to control the Jaws assembly

void setup()
{
  Serial.begin(9600);
  myservo1.attach(3);
  myservo2.attach(5);
  myservo3.attach(6);
  myservo4.attach(9);
}

void loop()
{
  int a,b,c,d,e;
  // the a, b, c & c variables are used to retrieve value
from
  // analog pin 0, 1, 2 and 3, represent the relative
position
  // for the two joysticks.
  // The actual values for the center position and ranges
to
  // control the robotics arm movement are different,
based
  // on the components and material you use, and expected
  // to be different, which you need to check and calibrate
     // to yield the best control.
  // Left-right position for Joystick-1, range: 1023~0,
center: 497
  a=analogRead(0);
  // Front-back position for Joystick-1, range: 0~1023,
center: 508
  b=analogRead(1);
  // Front-back position for Joystick-2, range: 0~1023,
center: 490
  c=analogRead(2);
  // Left-right position for Joystick-2, range: 1023~0,
center: 500
  d=analogRead(3);
```

```
  // Value to control robotics arm assembly rotation. The
  // range for the rotation movement is about 20~160
degree
  a=map(1023-a,0,1023,20,160);
  // Set the value to Servo1 to rotate the robotics arm
  myservo1.write(a);
  Serial.print(a);
  Serial.print(",");

  // Value to control the rear arm's movement. The
  // range is 90~150 degree.
  b=map(1023-b,0,1023,95,150);
  Serial.print(b);
  Serial.print(",");
  myservo2.write(b);

  // Value to control the forearm's movement. The
  // range is 40~140 degree.
  c=map(1023-c,0,1023,40,140);
  Serial.print(c);
  Serial.print(",");
  myservo3.write(c);

  // Value to control the Jaws assembly, opening and
  // closing the Jaws. The range is 70~90 degree.
  d=map(1023-d,0,1023,70,90);
  Serial.print(d);
  Serial.print(",");

  myservo4.write(d);

  delay(15);
}
```

The rotating assembly at the base of the robotics arm can rotate approximately 70 degree in each direction. Servo movement to control the Jaws assembly is much smaller, within the 70~90 degree range to fully open and close the Jaws. The ranges and values in the above code listing is based on the servo and mechanical design we are using. The ranges and values are expected to be different when you use different type of servo and a different mechanical design.

In the above code listing, the input variable for the myservo.write() function to control servo movement is the actual degree, relative to the control arm attached to the servo motor. For example, a 30 degree move to the left from the center position is equivalent to 120 degree position, where the right-most position is 0 degree. However, calling this function with the same value can yield different result using servo motor from different manufacturer. For the application code to achieve more consistence control using the same value with different servo motors, the myservo.writeMicroseconds() function yield better result, which requires higher quality servo to properly interpret and process the signal.

Whether you are using the myservo.write() or myservo.writeMicroseconds() function, the input variable represent the servo's angle of movement, where the myservo.write() function take in a variable that in angular degree value. Whereas the myservo.writeMicroseconds() function take in a timing value that represent the servo's movement, such as:

- 500~2500us is equivalent to 0 ~ 180 degree movement

- Some servo is built with limited range of movement, 20~160 degree is equivalent to 800~2200us, 25~155 degree is equivalent to 900~2100us, 35~145 degree is equivalent to 1000~2000us and so on.

Depending on cost, quality and size of the servo, the range of angular movement can vary quite a bit. Prolong signal forcing the servo to move beyond its maximum range can permanently damage the servo.

# 6. Summary

Robotics arm is an interesting and challenging device that is entertaining, has great academic value and being used in real-life industrial automation and manufacturing environment. The introduction and hands on example in this application provide a starting point for help you get started. You can further advance your robotics arm knowledge using other information and resources that are readily available through the Internet.