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## Experiment M9 Remote Control Procedure

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Deliverables: Checked score sheet

### Overview

#### *Background*

Not all mechatronic systems are autonomous. Many are remote controlled by a human operator. For example, the NASA Mars rovers are controlled by operators millions of miles away on Earth. In this lab exercise, you will control the speed of a brushless motor and adjust the position of servo motors remotely using a 2.4 GHz transmitter and receiver—a system commonly used for RC cars, drones, and planes.

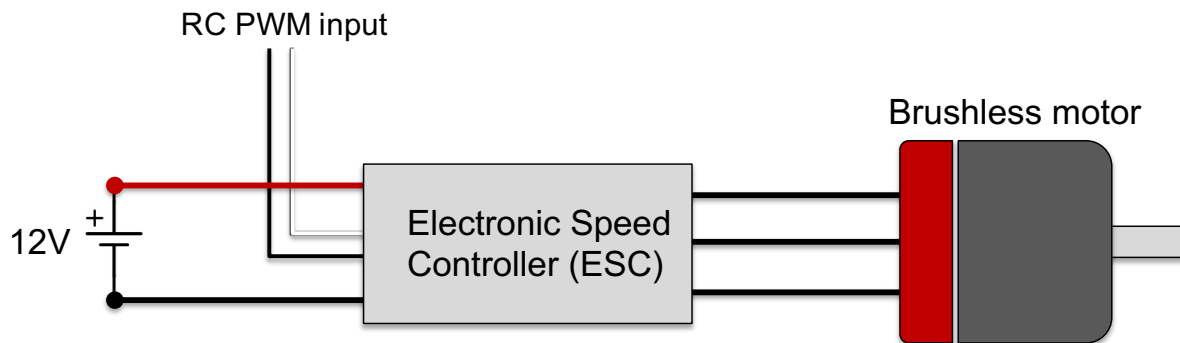
### Lithium Battery Safety – Standard Operating Procedures

1. Wear safety glasses whenever working with lithium batteries.
2. Inspect all batteries for damage before use. Do not use the battery if:
  - a. The case appears cracked or swollen.
  - b. The external cable insulation is damaged with the inner conducting metal exposed.
3. Charge all LiPo batteries with a proper charger-balancer.
4. Connect the battery to the charger-balancer and verify that all cells have sufficient charge before use.
5. An in-line fuse must be incorporated in any custom circuit that will be connected to a battery. The fuse should be immediately after the battery connector.
6. Do NOT remove the connector from the battery cables. This special connector ensures the battery cannot be accidentally short circuited or connected backward.
7. Lithium batteries should be stored and charged inside a special flame retardant bag or case.

## Part I: Brushless DC Motor

### Background

A brushless DC motor works similar to a stepper motor. It contains a series of electromagnetic coils that fire in succession causing permanent magnets connected to the shaft to spin. Unlike the stepper motor, the coils are driven by *3-phase power*. Each set of coil is driven by a separate AC sine wave, which are  $120^\circ$  out of phase with one another. Thus, the name “brushless DC motor” is a bit of a misnomer, because the motor actually runs on 3-phase AC sine waves. Shown below in Fig. 1, an *electronic speed controller (ESC)* is necessary to convert the 12V DC power to 3-phase AC power.



**Figure 1** – The brushless motor is connected to an ESC. The ESC takes in 12V DC power from a lithium polymer (LiPo) battery and a 50Hz digital pulse train, and outputs 3 phase power to the motor coils.

**Safety First!** – You must wear safety glasses when working with lithium (LiPo) batteries.

### Procedure

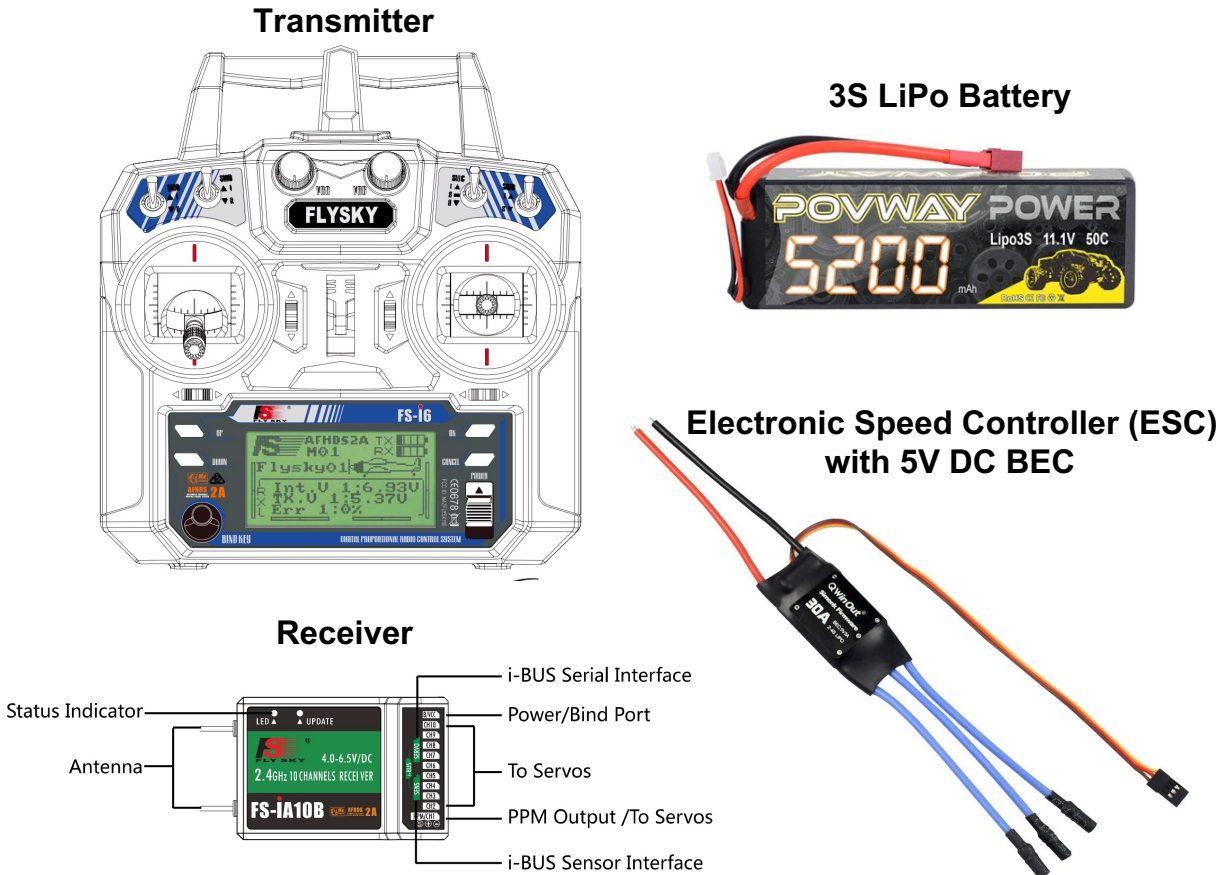
You will begin by connecting the brushless DC motor to the function generator. The ESC reads in a 50 Hz digital pulse with a width between 1000 – 2000  $\mu$ s. The width of the pulse tells the ESC what speed to turn the motor:

- 1000  $\mu$ s (1 ms) pulse width sets the angular speed to 0 RPM.
  - 2000  $\mu$ s (2 ms) pulse width turns sets the angular speed to its maximum value.
  - Any pulse width in between is linearly mapped to an angular speed between the two limits.
1. Connect the PWM input of the ESC to the function generator using male Dupont pin jumper wires. The yellow wire goes to the signal and the brown wire goes to ground.
  2. Use the function generator to produce the PWM signal via the “Pulse” function with a frequency of 50 Hz, a high value of 5V and low value of 0V.
    - a. Select the function type to be “Pulse” by pressing the “Pulse” button.
    - b. Press the “Amplitude/High” button. Set the “High Level” to 5V and the “Low Level” to 0V.

- c. Press the “Frequency/Period” button, and set the frequency to 50 Hz.
  - d. Press the “Duty/Width” button and set the duty cycle to 10% (pulse width of 2000  $\mu$ s).
3. Connect the 3 wires on the brushless motor to the ESC. It does not matter what order you connect them in.
4. Turn on the output of the function generator.
5. Connect the thick red and black wires on the ESC to the 3S LiPo battery using the red Deans T adapters. You should here a few beeps from the motor.
6. After the beeps, set the duty cycle to 5% (pulse width of 1000  $\mu$ s). (This simulates an RC drone pilot turning the throttle down to a “safe position”.) You should here more beeps indicating that the motor is armed.
7. Test the motor. Use the arrow keys below the big wheel knob to move the cursor over to adjust the duty cycle by 0.1% increments. Increasing the duty cycle should increase the angular speed, with 5% duty being completely OFF and 10% duty cycle being full throttle.
8. Try swapping any two of the three motor cables. This should change the direction that the motor spins.
9. **Demonstrate the working motor to the TA or lab instructor to receive credit.**
10. Disconnect the ESC from the function generator, and turn off the function generator.

## Part II: Remote Control

The remote control system consists of a transmitter and a receiver, as shown in Fig. 2. You will now replace the function generator with the receiver and use it to control the brushless motor and a few servo motors. The ESC contains a battery elimination circuit (BEC) that converts the 12V DC from the 3S Lithium-Polymer (LiPo) battery to 5V DC to power the receiver and servos.



**Figure 2** – (Left) The receiver receives the 2.5 GHz radio waves from the transmitter, and uses the information from the radio signal to produce a series of 50 Hz pulse trains, which can be used to drive servos and brushless motors. (Right) The ESC is used to distribute power from the battery to the brushless motor, receiver, and servos.

**Safety First!** – You must wear safety glasses when working with lithium (LiPo) batteries.

### Procedure

1. Connect the 3S LiPo battery to the ESC using the red Deans T connectors.
2. The receiver and servos need 5V DC to operate. Luckily, the ESC has a DC-DC converter known as a Battery Eliminator Circuit (BEC) that can provide this 5V DC power. Connect the small 3-wire connector on the ESC to the B/VCC pins on the receiver, such that the ground wire (brown or black) is on the bottom. You should see an LED light up on the receiver.

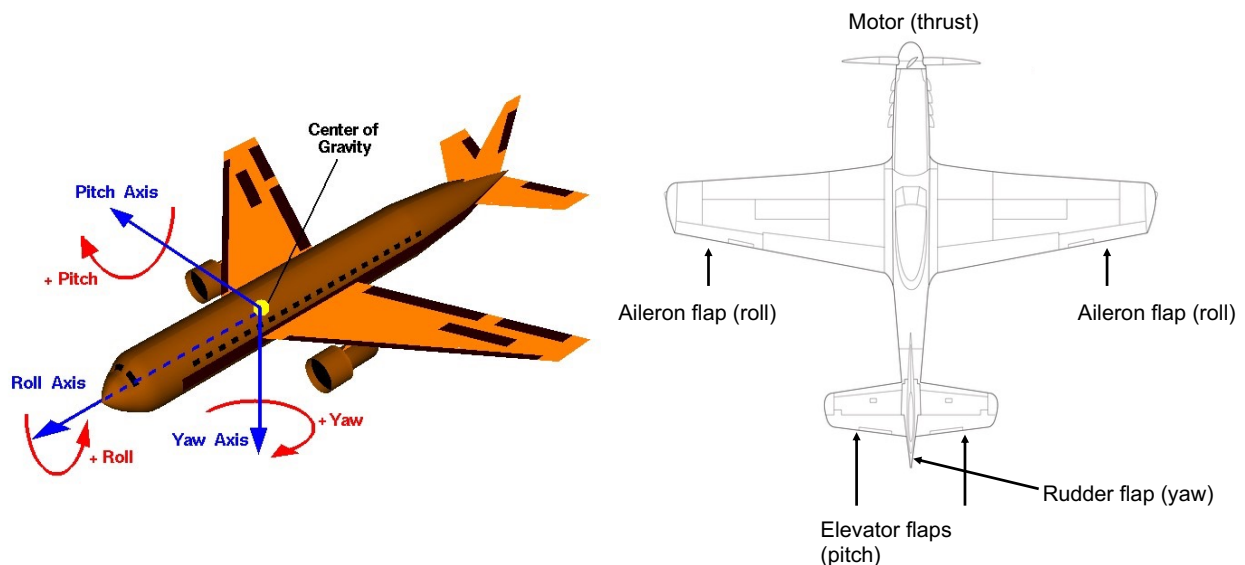
3. Turn on the transmitter. The bottom of the screen should say “SigS1: 10”. If the bottom line of the screen is blank, ask the lab instructor or TA for help.
4. Use the oscilloscope to measure the digital signal output by CH1 on the receiver.
  - a. Connect female-male Dupont pin jumper wires to the top pin (signal) and bottom pin (GND).
  - b. Connect the jumper wires to the oscilloscope using a BNC to minigrabber cable. Remember, the black minigrabber always goes to ground.
  - c. Sketch the digital pulse train in your lab notebook.
  - d. Adjust the joysticks and knobs on the transmitter. Which one adjusts the pulse width on CH1?
5. Connect the first 6 channels to the oscilloscope. Adjust the joysticks and knobs on the transmitter to determine which channel is controlled by which knob. **Record the mapping in your lab notebook.**
  - Left joystick up-down → CH??
  - Left joystick side-to-side → CH??
  - Right joystick up-down → CH??
  - etc.
6. Move the ESC over to CH3 on the receiver. Hold the left joystick (throttle) all the way down. You should hear the motor beep, as it did in Part I. Use the left joystick to adjust the speed of the brushless motor.
7. Connect one of the small servos to another channel on the receiver. Use the corresponding joystick to control the angle of the servo shaft.
8. **Show the TA your lab notebook and demonstrate the working system to the TA to receive credit on your scoresheet.**

## Design Challenge 1 – Flight Control System

You will now design a Human-Machine Interface (HMI) for an operator to fly a remote controlled aircraft. Shown in Fig. 3, the thrust and attitude (pitch, roll, and yaw angles) of an aircraft are controlled by various mechanical actuators.

- Thrust force is controlled by adjusting the motor speed.
- The attitude (angular orientation) is controlled by adjusting the position of servo motors.
  - Pitch angle is controlled by adjusting the elevator flaps on the tail.
  - Roll angle is controlled by adjusting the aileron flaps on the wings.
  - Yaw angle is controlled by adjusting the rudder flap on the tail fin.

In an RC plane, the flap are adjust using small servo motors, and the propeller is connected to a brushless DC motor.



**Figure 3** – The attitude (pitch, roll, and yaw angles) of an aircraft are controlled by various flaps. The thrust is controlled by adjust the propeller motor speed.

Design a system for an operator to fly an RC plane using the remote control and actuators provided. It should have the following features.

- Left joystick up-down should control the motor speed (thrust).
- Left joystick side-to-side should control the rudder flap (yaw).
- Right joystick up-down should control the elevator flaps (pitch).
- Right joystick side-to-side should control the aileron flaps (roll). The aileron flaps use two separate servos connected to the same channel. Use the Y-cable to split the signal from the receiver channel.

Place the four servos and the brushless motor in the appropriate locations on the printed drawing of the aircraft. **Demonstrate the working system to the TA to receive credit.**

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## Design Challenge 2 – 2-Axis Pan-Tilt

In the M3 lab, you used a single servo to aim the foam nerf dart in 2D space. However, many applications require parts to be aimed in 3D space via rotation about two perpendicular axes (pan-tilt or alt-az axes). Common examples include robotic arms or a pan-tilt camera mounts.

In this design challenge, you will construct a system where a user can adjust the angular orientation of an arm or camera using a joystick on a remote control. To receive credit, your system must be able to point a rod at any position specified by the TA or lab instructor.

### *Procedure*

1. You will not use the brushless motor, but you will still need the ESC and LiPo to power the receiver and servos with 5V from the battery elimination circuit (BEC). Connect the small 3-wire connector on the ESC to the B/VCC pins on the receiver, such that the ground wire (brown or black) is on the bottom. You should see an LED light up on the receiver.
2. Test both continuous servos with the RC receiver. You should be able to control their angular speed with a joystick.
3. Disconnect the servos from the RC receiver, and mount them in the GoBilda servo blocks. The servo blocks have an extra set of ball bearings to support the servo shaft. This allows for more weight to be mounted to the servo shaft. A schematic for assembling the servo blocks can be found in Appendix B.
4. Use the GoBilda hardware on the counter top to assemble both servos in a pan-tilt configuration, where the two servo axes are always perpendicular to each other.
  - a. All GoBilda hardware has both through holes and threaded holes for M4 screws. However, the servo discs are held to the servo shaft with a smaller size screw.
  - b. Various examples and ideas for mounting the servo blocks can be found on the product page linked below.  
<https://www.servocity.com/compact-servoblock-43mm-width-for-standard-size-h25t-spline-servo-hub-shaft/>
  - c. Use a U-channel to create a sturdy base. Clamps are available to secure it to the lab bench.
  - d. Use M4 screws to attach the square linkage rod to the servo disc. In robotics, this is often referred to as the “end effector”. You should be able to point this rod at any position specified by the TA or lab instructor.
5. Reconnect the servo wires to the RC receiver. Think about the user experience, and use the RC channels that will allow for the most intuitive controls. Test it with a couple different configurations and decide which is easiest. To receive credit, your system must be able to point square linkage end effector at any position specified by the TA or lab instructor.
6. **Demonstrate the working system to the TA to receive credit.**

## **Clean-up**

To receive full credit, you must return the lab bench to its initial state:

- Disconnect all the wires.
- Place the servo blocks, servo discs, and any hardware that came with them in a plastic bag and leave it on your lab bench.
- Any hardware you took from the counter top should be returned to its original place on the counter top.
- Put anything that belongs in your tool kit back into the tote bin.

## **Data Analysis and Deliverables**

You do NOT have to write a tech memo for this lab.



## Appendix A

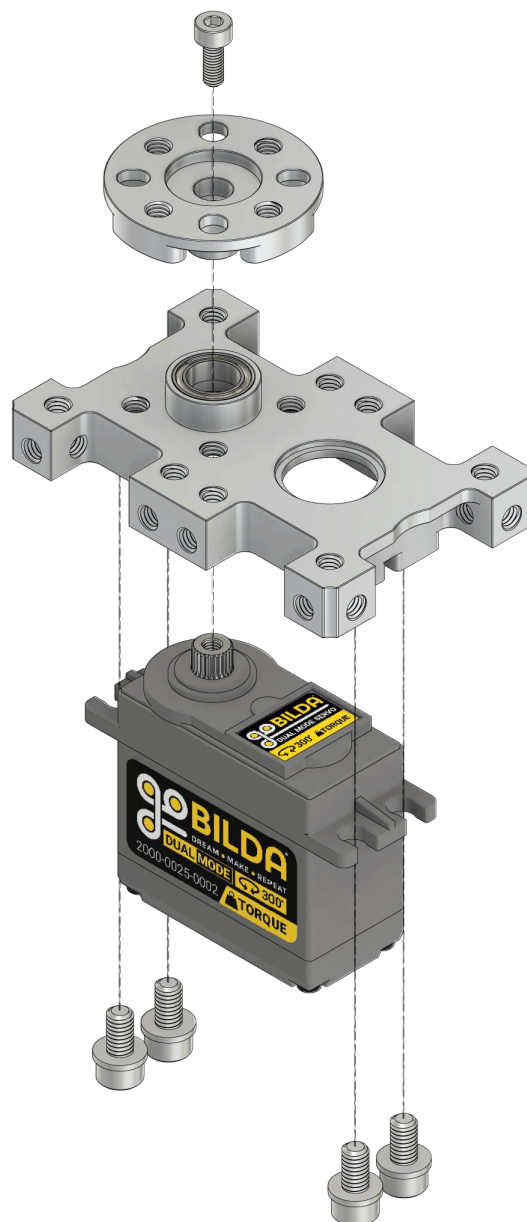
### Equipment

- 12V DC power supply (looks like a laptop charger)
- BNC to minigrabber cable
- Male-female Dupont pin jump wires
- Small servos
- Flysky FS-i6X 2.4G 10CH Radio Transmitter and Receiver iA10B – Amazon Part # B0B3T2R65X
- 30A Brushless motor ESC with 5V BEC – Amazon Part # B07SFLJJQ5
- 3S LiPo Battery, 5200 mAh with Deans T connector – Amazon Part # B088BX96DK
- ReadyToSky Brushless motor – Amazon Part # B075DD16LK
- Printed drawing of aircraft

## Appendix B



PRODUCT INSIGHTS



### 3217-0001-2501 Product Insight #1

The 3217-0001-2501 includes all hardware required to mount a standard size servo with an H25T (25 tooth) output.

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