SuperFly Integrated Flight Controller: Transmitter Set Up, Flight Operations and PID Tuning Methodology

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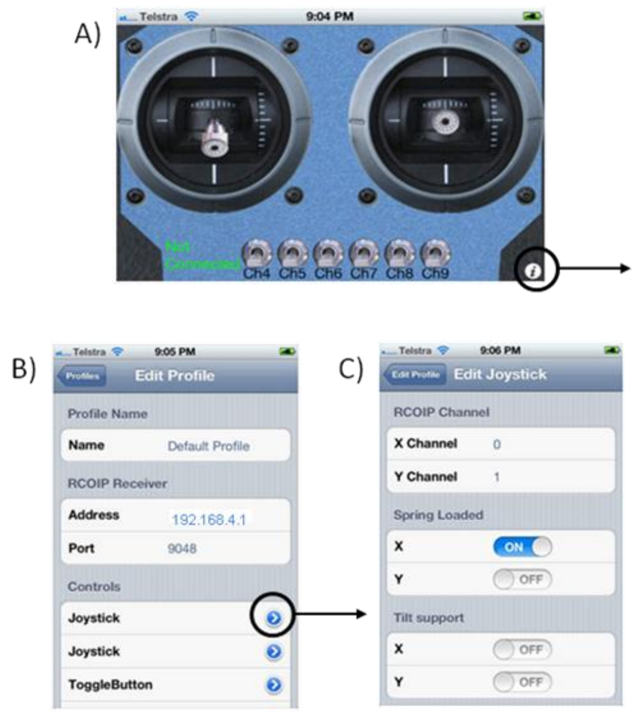
The purposes of this document are to: 1) Instruct the user regarding the setup of the RCTx iOS App, 2) Executing flight mode and calibration commands by transmitter joystick position combinations, 3) Basic UAV flight instruction, and 4) Basic PID tuning methodology. It is assumed that the user has already read the initial document entitled, "SuperFly ESP8266/EM7180-Based Integrated Flight Controller". This previous document focused on the SuperFly flight controller proper, the corresponding Arduino sketch, the supporting software tools, basic controller configuration and key IMU calibrations. These subjects are crucial to properly integrate the SuperFly into a quadcopter but there are additional configuration and operational aspects that must be understood for successful UAV flight. The following sections will cover subjects such as iOS RCOIP transmitter App setup, safe operation of the craft using transmitter joystick commands, adjusting or "Trimming" the aircraft flight characteristics for optimal performance and a useful methodology for "Tuning" the PID control loop constants for your particular airframe.

Transmitter Setup

The SuperFly Integrated Flight Controller can be radio controlled by two basic methods: 1) A "Conventional" commercially obtained RC transmitter and Pulse Position Modulation (cPPM) receiver or 2) 802.11x WiFi using "Radio Control Over Internet Protocol" (RCOIP). This is accomplished using an iOS device (iPhone or iPad) and the "RCTx" App that is available from the iTunes App Store (https://itunes.apple.com/us/app/rctx/id567423127?mt=8). It is assumed that users opting for commercial RC equipment are familiar with its setup and configuration or have specific documentation from the RC equipment supplier, so these will not be discussed further here.

To enable the RCOIP WiFi receiver, this option must be selected in the "config.h" tab of the Arduino sketch prior to compiling and uploading, as described in the "SuperFly ESP8266/EM7180-Based Integrated Flight Controller" document. Figs. 1A through 1C are screen shots of an iOS device running the "RCTx" App. Fig. 1A is a view of the main operating screen showing the joysticks and auxiliary function switches. In the lower right corner of the main screen is a small round white button with an "*i*" in the middle of it. Pressing this button will reveal a list of transmitter "Profiles". Select an entry from this list and the "Edit Profile" page will appear, as shown in Fig. 1B. Enter the desired profile name, IP address and receiver port. The profile can be given any name but the IP address and receiver port must assume the correct values to establish the RCOIP WiFi link with the SuperFly flight controller. **The IP address must be "192.168.4.1" and the receiver port must be "9048".** These settings will work for all SuperFly flight controllers. Finally, press the right arrow button for the first "Joystick" entry in the “Controls” list and the “Edit Joystick” page will appear as shown in Fig. 1C. This page addresses the left-hand joystick. It is important to set the “Spring Loaded” setting for the Y-axis to “OFF”. This configures the Y-axis of the left joystick to be the UAV’s throttle. **IT IS CRUCIAL THAT THE THROTTLE NOT BE SPRING-LOADED SO THAT THERE IS NO UNEXPECTED VERTICAL ACCELERATION OF THE CRAFT WHEN THE THROTTLE JOYSTICK IS UNATTENDED! It is also highly recommended to set “Tilt support” for both axes of both joysticks to “OFF”. Otherwise, tilting the iOS device off of horizontal will send unintentional commands to the UAV!**

Figure 1. A screen captures of an iOS device running the “RCTx” App showing A) The main operating screen B) The main profile setup screen and C) Joystick setup screen.



Once the receiver parameters and joysticks are properly configured, tap the left arrow buttons on the upper bar of the edit screens until you are back at the “Profiles” menu. Finally tap the profile you just edited to get back to the main screen in Fig. 1A. The RCTx App is now properly configured for use with the SuperFly flight controller.

Now that the RCTx App is configured, it still remains to establish the WiFi link between the iOS device and the UAV craft. The ESP8266 node MCU on the SuperFly flight controller board is actually configured as a wireless access point. In order to pair the UAV to the iOS device:

1. Power up the SuperFly flight controller/UAV craft
2. On the iOS device, navigate to the “Settings” -> “WiFi” page
3. Ensure that the “Wi-Fi” switch is set in the “ON” position

4. Under the available networks, you should see a network with “ESP8266 SuperFly” as the leading string with additional alphanumeric characters appended
5. Select this network; you should then be prompted for a network password. **The password is “letsflynow”**
6. Once the iOS device has successfully connected to the SuperFly flight controller, navigate back to the RCTx App. The “Not Connected” string in the lower left corner of the RCTx main screen should disappear and be replaced by a string indicating the LiPo battery voltage. Seeing the battery voltage indicated on the lower left is a certain indication that the RCIOP link between the iOS device and the UAV is properly established.
7. In the event the iOS device connects to the “ESP8266 SuperFly….” network but the battery voltage indication does not appear, the RCTx App may need to be reset. To do this, kill the RCTx app with the simple procedure described online (http://www.imore.com/how-kill-or-force-quit-apps-iphone-ipad) and re-start it or simply power-cycle the iOS device

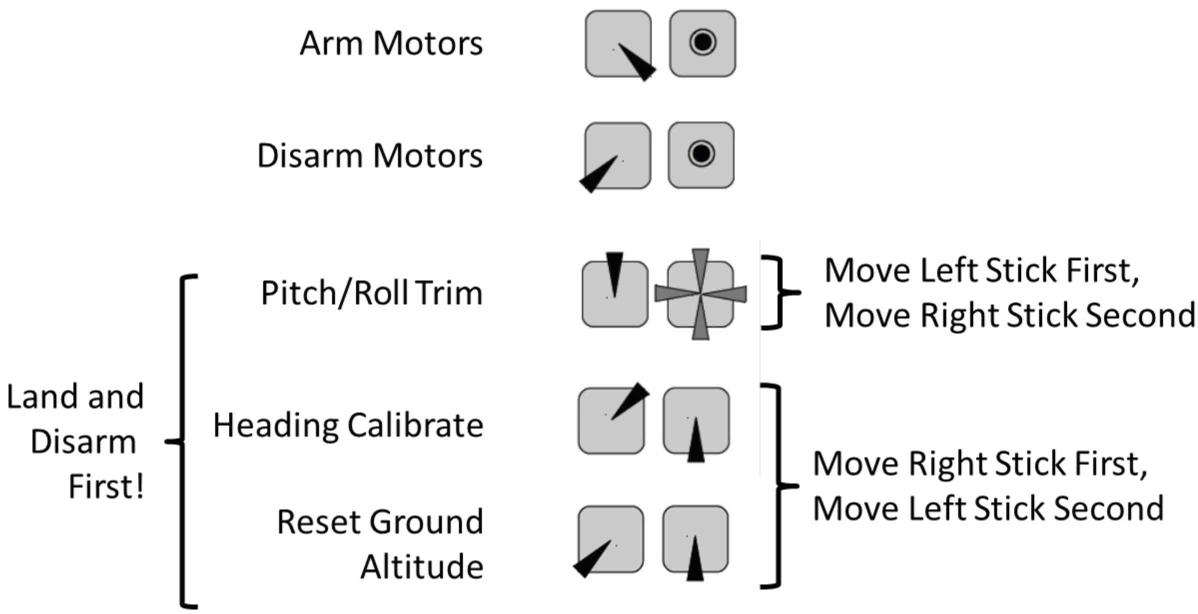
Enhanced Transmitter Joystick Functions

At this point, the chosen transmitter option should be properly configured for use. It would be good to connect the UAV to the SuperFly configurator GUI and verify on the receiver tab that the flight controller is getting valid RC signals. Also take this opportunity to review the mode selection tab and verify that the flight modes are configured as desired. It is recommended that the “HORIZON” and “HEADFREE” flight modes are the default. It should also be noted that the altitude control is interlocked to prevent unexpected takeoff of the UAV. The “BARO” mode MUST be off in the default configuration or the SuperFly will not arm the motors and flight will be impossible. Check that the desired transmitter auxiliary function switches modify the SuperFly flight modes in the desired manner. Refer to the configurator GUI overview section of the “SuperFly ESP8266/EM7180-Based Integrated Flight Controller” document if necessary.

The two transmitter joysticks constitute the basic flight controls for the UAV. The SuperFly controller is set up for “Mode 2” transmitter joystick configuration. This means the horizontal axis of the right-hand joystick controls roll (left-right) while the vertical axis of the same joystick controls pitch (forward-backward). The horizontal axis of the left-hand joystick control yaw (heading) and the vertical axis of the same joystick is the throttle. In addition to these basic flight controls, the transmitter joysticks are used to control enhanced functions of the SuperFly flight controller when they are moved to their extremes in certain combinations. These combinations are intended to be essentially impossible to trigger unless a deliberate action is taken by the user. **However, it is not a good idea to randomly manipulate the joysticks in an extreme manner with no clear purpose in mind as this could potentially result in unintended response from**

the UAV. Fig. 2 shows schematic representations of the active enhanced joystick position combinations and their associated functions.

Figure 2.Schematic images of transmitter stick positions that actuate special higher-order flight controller functions. These include arming and disarming the main motors, applying pitch and roll angle trim, heading calibration and resetting altimeter ground altitude.



These functions include:

- Arming the flight motors
- Disarming the flight motors
- Providing pitch and roll angle "Trim" offsets to prevent the craft from wandering during hover
- "Heading calibration" which stores the current state of the EM7180 heading estimation to EEPROM so it will be retrieved at the next boot-up
- Resetting the ground altitude value of the altitude controller

Perhaps the most important safety feature for any multirotor UAV is the Arm/Disarm feature of the flight controller. Although it is crucial for the pilot to pay proper attention to the state of the craft at all times, the Arm/Disarm feature avoids many accidents by preventing unintentional power-up of the flight motors. **The SuperFly flight controller boots up with the disarmed state as the default.** Furthermore, it is not possible to arm the SuperFly flight controller until the RC link is established and valid RC control signals are being received. **Before attempting to arm, the UAV should be roughly level and the altitude hold flight mode must be deactivated. If the blue LED on the SuperFly board is blinking, that means the craft is**

tilted more than 25 degrees and it will not arm. Arming is accomplished by moving the left-hand transmitter joystick to the extreme lower-right corner of its travel while the right-hand joystick is neutral. **Arming is successful when the blue LED on the SuperFly board comes on steady. BE AWARE THAT THE CRAFT IS NOW ARMED AND THAT MOVING THE THROTTLE JOYSTICK FORWARD FROM ITS MINIMUM POSITION WILL CAUSE THE FLIGHT MOTORS TO RUN.** Disarming is accomplished by moving the left-hand transmitter joystick to the extreme lower-left corner of its travel while the right-hand joystick is neutral. **Disarming is successful when the blue LED on the SuperFly board goes out.** The craft is now safe from accidental power-up of the flight motors.

The three remaining enhanced transmitter joystick functions shown in Fig. 2 have to do with fine-tuning or “Trimming” the craft’s pitch and roll angles at neutral joystick position and performing two different in-field calibrations that can be performed during a flying session.

The need for pitch and roll trim values arises because it is never possible to have the SuperFly board mounted perfectly level on the UAV frame. Before attempting to use the pitch/roll trim feature:

- Ensure that the SuperFly board is properly mounted to the UAV craft’s frame, *i.e.* it is not obviously tilted
- Ensure that the UAV craft is properly balanced. The center of gravity should be at the geometric center of the UAV frame. Typically, the single largest cause of imbalance is from the LiPo battery not being mounted at the geometric center of the craft.

If the SuperFly board is obviously tilted or the UAV frame is significantly unbalanced, no amount of pitch/roll trim will make up for these underlying faults. It is highly recommended to resolve these problems before proceeding.

As an example, let us say that the UAV craft in being flown in either the “ANGLE” or “HORIZON” flight mode and the craft consistently drifts to the right while hovering. To use the pitch/roll trim feature to correct this problem:

1. If applicable, ensure that the pitch and roll trims on the RC transmitter are set to neutral
2. If the craft still drifts to the right, **land and disarm it. The blue led on the SuperFly board should be off**
3. **BE CERTAIN THE CRAFT IS DISARMED!** Then, move the throttle joystick (left-hand, Y-axis) to the full position. Move the roll joystick (right-hand, X-axis) fully to the left and hold it until you see a brief flash from the blue LED on the SuperFly board
4. When you see the brief LED flash, that means a trim value of “Left 0.02^o” has been stored to the EEPROM and will now be applied to the calculated roll angle during flight. Each angle 0.02^o angle correction is often referred to as a “Click”
5. If you continue to hold the roll stick fully to the left, the SuperFly will add continue to add “Left clicks” to the roll angle correction at the rate of one every few seconds. Every

time you see the blue LED flash, another “Click” has been added to trim correction and stored to the SuperFly’s EEPROM

6. When you think enough trim “Clicks” have been added, move the throttle joystick back to the minimum position
7. The craft may now be re-armed and test flown to assess the effect of the added trim

If the craft still drifts to the right then land the craft, disarm it, put the throttle joystick to full, add some more left-clicks, re-arm and test fly again. This process is done iteratively in the same manner for either direction of the pitch and roll axes until the craft will hover without consistently wandering in any specific direction.

One of the key features of the SuperFly flight controller is “Headless or “Carefree” flight where the pilot’s perception of left/right and forward/backward is invariant with respect to the craft’s heading. The basic procedure for performing the heading calibration on the SuperFly board is discussed in detail in the document entitled “SuperFly ESP8266/EM7180-Based Integrated Flight Controller”. However, there are instances where the EM7180’s heading estimation algorithm has not fully relaxed to its final state during the calibration procedure. If this is the case, sometimes the pilot can perceive that the control axes are skewed, meaning there is some interaction between pitch and roll joystick commands. Although this seldom needs to be done, the current state of the heading estimator can be stored to the EEPROM at any time using specific joystick commands:

1. **Land the craft and disarm it. The blue led on the SuperFly board should be off**
2. Make sure the front of the craft is pointing exactly AWAY from you
3. First, pull the pitch joystick (right-hand, Y-axis) all the way back toward you. Then move the left-hand joystick to the extreme upper-right corner as shown in the “Heading Calibrate” schematic of Fig.2. Hold this combination of joystick positions for 1-2s
4. Return the throttle to its minimum position and let the other joystick axes return to neutral
5. Re-arm and resume normal flight

Finally, the ground altitude of the SuperFly’s altitude controller can also be reset using stick commands. This is largely a troubleshooting feature because the ground altitude is automatically reset when the SuperFly flight controller has first been armed and then disarmed. However, if the pilot wishes to reset the ground altitude, it can be accomplished as shown in the “Reset Ground Altitude” schematic of Fig. 2:

1. **Land the craft and disarm it. The blue led on the SuperFly board should be off**
2. Make sure the craft is sitting still on the ground
3. First, pull the pitch joystick (right-hand, Y-axis) all the way back toward you. Then move the left-hand joystick to the extreme lower-left corner. Hold this combination of joystick positions for 1-2s

4. Return the throttle to its minimum position and let the other joystick axes return to neutral
5. Re-arm and resume normal flight

Basic Flight Operations

After reading and following all of the documentation to this point, the user should have a functional SuperFly-based quadcopter. The purpose of this section is to give new pilots some basic instruction on how to effectively fly their UAV.

Select an appropriate location for flying your quadcopter. Indoors in a fairly large room is a common and suitable choice. Flying outdoors is also an option but wind can be a complicating factor. It is recommended that outdoor flying be done under calm conditions. The following bullet points are intended to serve as a general guideline and also provide some additional SuperFly-specific detail:

- **Make sure you have a fully charged battery**
- **Check battery installation.** Before powering up the UAV, be sure that the battery is properly located on the frame to provide the proper balance. Poor balance is the cause of many undesirable flight characteristics
- **Set the craft in the right location.** Place the craft on the surface intended for takeoff and landing. The UAV should be roughly level, in front of you and facing away from you
- **Power up.** Connect the SuperFly board's power connector to the battery and let the craft sit still for approximately 10s. During this brief period, the EM7180 sensor fusion coprocessor will collect gyroscope data, calculate the necessary gyroscope sensor biases and apply them to the gyroscope sensor data streams
- **Verify radio control is working.** Check that the RC link has been established. For the conventional cPPM RC option, typically an indicator LED on the receiver will come on when sync with the transmitter is achieved. For the RCOIP option, the LiPo cell voltage will be indicated on the lower-left corner of the RCTx main screen
- **Verify the correct flight mode.** For initial flight testing, a combination of the "HORIZON" and "HEADFREE" modes are recommended; set the RC transmitter auxiliary switches accordingly. Verify that the "BARO" mode is not active
- **Arm the UAV.** Stand behind the craft with the front facing away from you. Arm the craft by pulling the left joystick to the extreme lower-right corner until the blue LED on the SuperFly flight controller board comes on. Release the left joystick; the throttle should be at the minimum and yaw/roll/pitch should all be in the neutral position

- **Verify motor function and correct propeller rotation.** Carefully increase the throttle a small amount and verify that all four motors are running. Double-check that all motors are running in the correct direction. If not, troubleshoot and take corrective action so that all motors will run and rotate in the correct direction
- **Get a feeling for the throttle level required to hover.** Carefully increase the throttle level until the craft starts to generate enough lift to overcome gravity; take note of the approximate throttle level where the craft starts to lift off. Carefully repeat several times until you start to get a feel as to where the craft will break free of the ground. It should be noted that bringing the throttle up very slowly through the hover point is likely to cause the craft to slide laterally. This is caused by the "Ground effect" and is normal
- **Try to hover the quadcopter.** Arm the craft with it in front of you and facing away. Move the throttle smoothly and deliberately through the hover point so that the craft rises several feet above the ground. The initial goal is to learn how to smoothly break free of the ground effect and hover the quadcopter without hitting the ceiling. If you feel the craft is "Getting away" from you, deliberately move the throttle back down through the hover point to set it back down on the ground. Practice until you feel you are in control of the craft's altitude
- **Always mind whether or not the craft is armed.** Remember, landing the quadcopter does not render it safe! Always disarm after landing unless you intend to fly again immediately
- **Trim the quadcopter so it will be stable with the joysticks in neutral.** If you notice that the craft "Wanders" with the pitch/roll/yaw controls in neutral, it requires "Trim" adjustments. Pitch and roll trim is accomplished by the method outlined in the "Enhanced Transmitter Joystick Functions" section of this document. If using a conventional RC transmitter, be sure that the trim settings are at neutral before using the enhanced joystick command procedure to set pitch/roll angle trim offsets in the EEPROM. Typically, yaw trimming should not be necessary. If the craft has a consistent heading (yaw) drift, that is usually due to some defect with the propellers, motors, or motor alignment. In such cases adding trim values will most often not resolve the problem and the underlying defect must be fixed. It should also be noted that the need for excessive pitch/roll trim (more than ~20 "Clicks" in any direction) might also indicate some underlying defect with the craft that needs to be resolved
- **Don't overfly your batteries!** For the moment, the SuperFly flight controller does not have an automatic low voltage handling failsafe routine. If you are using the RCOIP transmitter option, you can watch the cell voltage degradation as the flying session progresses. The battery should never be discharged below 3.4V. For the conventional RC transmitter option, it is recommended to use the transmitter's timer. For the U816-based frame, the craft can be flown safely for ~4min using the 240/250mAh battery, ~6min using a 380mAh battery and ~8min using a 500mAh battery. **WARNING! IF YOU**

PUSH THE FLYING TIME TOO FAR, THE SUPERFLY BOARD WILL "BROWN-OUT", CAUSING UNPREDICTABLE RESULTS!

- **Get comfortable flying the craft.** Assuming that the craft has been successfully constructed and trimmed, it now remains to improve your piloting skills. In other words, practice, practice, practice!
- **Try some of the other flight modes.** Once comfortable with basic flight in the "HORIZON" mode, try deactivating it to fly in the "ACRO" mode. The craft will be quite agile but will not be self-righting. Also use the altitude hold ("BARO") mode to keep the craft at a reasonably steady altitude. Be sure to establish a stable hover at the desired altitude before engaging the altitude hold. Disengage the altitude hold to resume normal throttle control or change altitudes

PID Tuning Methodology

The SuperFly Integrated Flight Controller comes with pre-programmed defaults for the Proportional-Integral-Derivative (PID) tuning parameters. Using these defaults, small brushed-motor quadcopters (~90-120mm "Wheelbase") should be stable in their flight performance. PID tuning problems usually manifest themselves as pitch/roll oscillation or "Wobbling". The rest of this section will be devoted to discussing the various causes for airframe instability and appropriate PID tuning methodology for the SuperFly flight controller.

There are several PID control loops implemented in the SuperFly flight controller. The PID algorithm is one of the oldest and most widely used forms of closed-loop process control. Although the PID approach has well-known shortcomings, it is still widely used for flight control. There are many good explanations of the basic PID control theory available for review so it will not be discussed in detail here (http://www.ni.com/white-paper/3782/en/). However, there are a few basic points that are helpful to understand the specific tuning process for the SuperFly flight controller:

1. There are three basic kinds of control signals:
   a. Proportional Error - How far is the response sensor from the set point? This is basically the coarse adjustment
   b. Integral Error - The product of how long and how far away the response sensor has been from set point. This term takes over when the response sensor is close to the set point and the proportional error term has become small. The integral error is the fine adjustment that gets the system that last little way to the set point
   c. Response Derivative – This term comes into play when there is "Lag time" in the control loop so that the system tends to "Overshoot" the set point before the response sensor can detect that the system has over-corrected

2. There is a separate gain for each control signal; one for the proportional error, one for the integral error and one for the response derivative.

3. The P, I and D gains determine the stability and dynamic response of each control loop. In general, instability and oscillation are caused by excessive P and I gain. The fundamental factors that limit the maximum gains are the response time of the system being controlled and the lag time of the response sensor feedback loop

A brief note about the derivative term is in order here. In classic PID theory, the derivative term is SUBTRACTIVE. That is to say, if the system is moving too fast toward the set point, the derivative term detects this and slows the response down so that the system doesn't overshoot the set point. Many multirotor flight controllers such as "MultiWii", "Baseflight", "Cleanflight", 3D Robotics, *etc*. use an ADDITIVE derivative term. That is, the derivative term acts as additional proportional gain. This is supposedly to make the craft respond more quickly to stick commands… But this approach can also de-stabilize the craft and greatly complicate the PID tuning process. **The SuperFly flight controller uses SUBTRACTIVE derivatives in accordance with classic PID theory. Moreover, all efforts have been made to minimize the response sensor lag times so that in the vast majority of cases NO DERIVATIVE GAIN IS NECESSARY.** Except where noted, all attempts to achieve stability are most efficient when the derivative gain is neglected and left at zero.

In order to adjust the PID constants it will be necessary to use the SuperFly configurator GUI described in the "SuperFly ESP8266/EM7180-Based Integrated Flight Controller" document. The PID constants are shown and updated on the "PID Tuning" tab. The various control loops are:

- "ROLL" - This loop controls the angular rate of the craft in the roll axis. The response sensor is the output of the "Roll" gyroscope. The output of this loop directly influences the quadcopter's motor speeds. P, I and D terms in this control loop are active
- "PITCH" - This loop controls the angular rate of the craft in the pitch axis. The response sensor is the output of the "Pitch" gyroscope. The output of this loop directly influences the quadcopter's motor speeds. P, I and D terms in this control loop are active
- "YAW" - This loop controls the angular rate of the craft in the yaw axis (heading). The response sensor is the output of the "Yaw" gyroscope. The output of this loop directly influences the quadcopter's motor speeds. P, I and D terms in this control loop are active
- "LEVEL" - This loop controls both the pitch and roll angles of the craft. The response sensors of this loop are the pitch and roll angles calculated by the EM7180 sensor fusion coprocessor. The outputs of this loop control the set points of the "PITCH" and "ROLL" control loops when the craft is in either of the "ANGLE" or "HORIZON" flight modes. The P and I terms in this control loop are active. The D term is also active but does not assume its conventional meaning. It is an output limiter that determines the maximum

amount of correction the "LEVEL" control loop can apply to the "PITCH" and "ROLL" control loops

- "MAG" - This loop controls the heading of the craft while in the "MAG" or "HEADFREE" flight modes. The heading is set when the craft is armed or in the "HEADADJ" flight mode. The response sensor of this loop is the heading angle calculated by the EM7180 sensor fusion coprocessor. The output of this loop controls the set point of the "YAW" control loop. Only the P term is active
- "ALT" - This loop is the automatic altitude controller while in the "BARO" flight mode. The response sensor of this loop is the inertial-enhanced barometric altitude error signal calculated by the EM7180 sensor fusion coprocessor. The output controls the flight motor throttle setting in lieu of the throttle joystick. The P and I terms are active in this loop and assume their conventional meaning. The D term is also active but the derivative control signal is actually taken from the vertical velocity "Variometer", which is an intermediate signal in the barometric-inertial sensor fusion algorithm. Use of the D term in this loop is necessary
- "VGS" - or "Vertical Gain Scheduling" for the "ALT" control loop. This is to help even out the asymmetry of the UAV's throttle response. For a small *decrease* in throttle setting, the craft will usually fall faster than it will rise for an equivalent *increase* in throttle setting due to gravity. These factors increase the positive vertical response of the craft when the altitude control loop tells the craft to rise. For the kind of small craft for which the SuperFly flight controller is intended, typically leave the "Integral" set to 0.255 and the "Derivative" set to 255. Decreasing the "Proportional" term makes the correction more aggressive while setting it to 0 will deactivate the vertical gain scheduling feature

In the vast majority of instances, the PID constants only need to be adjusted when the pilot observes that the craft is oscillating in the pitch and/or roll axes. First be sure that there are no obvious problems with the sensor calibrations and airframe. If the accelerometer calibrations have not been performed, be sure to complete them as per the instructions. The most common cause for airframe-based stability performance problems is excessive vibration from poor propeller balance. If there is any suspicion that the propellers are not properly balanced, do so. Typically, propellers for tiny quadcopters are "statically" balanced on a simple test fixture. There are many references on the internet for static propeller balancing (https://forum.bitcraze.io/viewtopic.php?t=737) so the topic will not be discussed in detail here. Many different means can be used to modify blade weight; sanding material off or adding weight by attaching "Scotch tape", paint or nail polish. All of these approaches will work.

If double-checking the propeller balance does not yield any improvement, it is time to address the PID tuning constants. First, it is necessary to determine which control loops are oscillating. As a first step, disable the "ANGLE" and "HORIZON" flight modes so that the craft is in "ACRO" mode. In this state, the craft is only being stabilized by the gyroscopes. BE CAREFUL IF YOU HAVE NOT FLOWN IN THIS MODE BEFORE. THE CRAFT WILL NOT BE SELF-

RIGHTING BUT WILL STAY IN THE ATTITUDE IN WHICH YOU LAST PUT IT. If the quadcopter stops oscillating in "ACRO" mode that means the "ANGLE" loop gain is too high. If the oscillations persist, that means the pitch and/or roll loop gains are too high. If you determine the angle loop gain is too high, start reducing the angle P-gain approximately 5-10% per iteration until the oscillations die down. The angle I-gain is typically 0.004 – 0.010. If the I-gain is too high, the craft will *slowly* wobble in pitch and roll a small amount. If this appears to be a problem, slowly decrease the I-gain until the minimum 0.004 is reached. It is not recommended to set the angle loop I-gain below 0.004. A value of 20 is good for the angle-loop D-gain; this should not need to be modified.

If flying the craft in "ACRO" mode shows that the problem is not in the angle loop, often just reducing the pitch and roll P-gain is all that is necessary to squelch the oscillations. First try reducing the pitch/roll P-gain by 10% and test fly again in "ACRO" mode. If the oscillations appear to be getting better but are not fully gone reduce the pitch/roll P-gain by another 10%. This can be repeated several times. However, if the P-gain is reduced too far, the craft will become difficult to handle and will tend to "See-saw" in pitch and roll. If the pitch/roll P-gain has been reduced to the point where the craft becomes difficult to control but it still oscillates, put the P-gains back to their original values and try reducing the pitch/roll I-gain. Again, reduce the I-gain in increments of ~10%. If the I-gain is reduced too far, the quadcopter will not hold an attitude set when the joysticks are at neutral position. As a final note, if the quadcopter still has pitch/roll oscillations no matter how the pitch/roll P and I-gains are set, that usually indicates too much lag time in the pitch and roll control loops. Most often this is due to excessively large propellers for the motors being used. Make sure to keep this point in mind if experimenting with different varieties of propellers.

The "YAW" and "MAG" control loops are generally quite forgiving. The default values should work well for many different types of UAV's. If the craft spins in the yaw axis it is almost certainly due to some problem with the airframe. The most common issue is that one or more of the motor shafts are not vertical with respect to the plane formed by the propellers, imparting a net torque on the airframe. Check the alignment of the motors on their respective arms. The other known problem is mechanical malfunction of one or more of the motors. This can be checked by watching the motors spin down as the throttle is set to the minimum position. If one of the motors stops spinning much sooner than the others, it probably needs to be replaced. If the heading wanders try slowly increasing the yaw I-gain and/or mag P-gain. If the yaw response to joystick commands is sluggish, try slowly reducing the yaw P-gain. If the heading "Snaps back" toward the original heading after giving a yaw joystick command, try reducing the yaw I-gain.

If the SuperFly flight controller is being installed on an airframe of unknown flight characteristics, it may be necessary to determine the PID tuning "from scratch". There are several good references on the internet that describe the general method for PID tuning. This is an excellent reference showing the impact of various gain conditions on flight characteristics as well as a detailed tutorial on pitch/roll tuning and the relative effects of P and I-gain.

(https://www.youtube.com/watch?v=YNzqTGEl2xQ&list=PLE6LG1r9ePh_Nd1uWM7hd6S6Zh91MRHat)

The following bullet-points outline the general approach for airframe PID tuning:

- Set the craft in "ACRO" flight mode, set the pitch/roll I, D-gains to zero and start with the default pitch/roll P-gains
- Arm and attempt to fly the craft. If the P-gain is too high it will oscillate rapidly. If it is too low, the craft will "See-saw" in pitch and roll. Iteratively increase or decrease the pitch/roll P-gain in 5-10% increments until you determine the "Critical" gain where the quadcopter just starts to oscillate. Set the P-gains ~10% below the critical value
- In the same manner, set the pitch/roll I-gains to the default and determine the critical I-gain where the craft just starts to oscillate. In the case of the I-gains, the oscillations will be much slower than those observed for excessive P-gain. Again, set the I-gains ~10% below the critical vale
- At this point, the quadcopter should fly well in "ACRO" mode. Put the craft into the "HORIZON" or "ANGLE" flight mode, whichever is preferred. Set the angle loop PID constants to the default values. Arm and fly the craft; if it oscillates reduce the angle loop P-gain in 10% increments until it stops. Once the craft doesn't oscillate in the angle-controlled modes, bank it smartly and let the joystick go back to neutral. Observe how the craft self-rights back to level attitude. If it is sluggish, slowly increase the angle loop P-gain until the self-leveling performance is acceptable. If the roll angle overshoots during self-leveling, reduce the angle loop P-gain until the overshoot stops. If the craft slowly wobbles during hover with the pitch/roll joystick in neutral, slowly reduce the angle loop I-gain

As a final subject, the altitude hold controller will be discussed. It is entirely fair to say that the altitude control loop is by far the most challenging to tune. This is because the response time of both the altitude error signal and the throttle are much slower than any of the other control loops. Furthermore, the vertical gain scheduling needs to be set properly in order to make the positive and negative throttle response symmetrical. Consequently, patience and persistence are required to achieve satisfactory results. The suggested tuning method is:

- Set the altitude I and D-gains to zero with the VGS settings and altitude P-gain at their defaults. Arm the quadcopter and establish a stable hover outside of the ground effect and well below the ceiling. Engage the altitude hold; be prepared for the craft to oscillate vertically. Disengage the altitude hold if the craft is in danger of hitting the ceiling
- Observe the vertical oscillations; they should be symmetrical about the altitude set point and fairly rapid. If there are no vertical oscillations or if they are very slow, increase the P-gain. If the craft falls further below set point than it climbs above set point, decrease the VGS proportional gain

- Once the quadcopter is oscillating symmetrically about the altitude set point, adjust the altitude P-gain so that the oscillations are fairly rapid and about 1-2ft in amplitude. Increase the D-gain until the oscillations subside. The D-gain should be approximately 10-15
- Altitude hold should be fairly stable. If the craft maintains altitude below the altitude set point, increase the altitude I-gain until the altitude hold is both stable and at the requested set point