HW1

Fuzzy-PID Altitude Hold

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1. ROSFLIGHT INTRO

ROSflight is open source autopilot software that runs on a small embedded flight controller. A companion computer can be used to recieve sensor data from the flight controller and send back commands. Since ROS integrates well with the Gazebo physics simulator I am testing plane controls in simulations only this term. This is mainly so I can safely "crash" the plane a lot while learning how to program flight controls.

2. SETUP

I. Operating System

I HIGHLY recomend using Ubuntu for setting up ROSflight. The latest supported version of ROSflight requires ROS Melodic on Ubuntu 18.04. Which is a bit unfortunate since 18.04 is already out of LTS. Though there is work on getting it ready for ROS2. Some libraries I used such as Scikit-Learn's fuzzy controller requires manual installation of a later Python version than what is supported by 18.04.

II. Roslaunch

I followed the guides on the official ROSflight website cover the installation of ROS, ROSflight, and the Gazebo simulator. I modified the default Roslaunch file for simulating a fixed-wing aircraft to include rosflight_joy, a companion node that binds keystrokes to a simulated Radio Controller to manually manuever the aircraft. The RC controller is necissary to "arm" the plane before the throttle can be activated. Since ROSflight is designed to run on an actual aircraft, there is a bit of configuration required begin simulations. You must calibrate the IMU and set the appropriate fixed wing parameters (i.e. tell ROSflight it is a plane and not a multi-copter). More details can be found in the official documentation. The modified roslaunch file is called myfixedwing.launch and it also includes links to two seperate world files I created. Both of these worlds are aifields but unfortunately the computer I am running the simulation on currently cannot render them in realtime, so they are currently disabled.

III. Gazebo

The Gazebo installation should happen along side ROSflight, but you may encounter the following error when first running a simulation:
[Err] [ModelDatabase.cc:235] No <database> tag in the model database database.config found here[`http://gazebosim.org/models/`]
[Err] [ModelDatabase.cc:294] Unable to download model manifests

The location of the model database has changed but has not been reflected in the gazebo package yet. The fix is to redirect to the correct URL before running the any launch files:
`export GAZEBO_MODEL_DATABASE_URI=http://models.gazebosim.org/`

The gazebo website is undergoing a major reconstruction at the moment. You should open up the URL above in a web browser too to check if the fix is still working.

3. ALTITUDE HOLD PID

The ROSflight node outputs a "Barometer" message that contains temperature, pressure, and altitude data. It also listens on the "Command" message for setting the plane's throttle, aeleron, elevator, and rudder control surface positions. I created a new node called altitudePID that subscribes to the altitude reading and publishes an elevator position command. The mapping of altitude inputs to elevator outputs was done with a PID controller from the "simple_pid" python library. The tuning of the PID gains was conducted with a trial and error approach. I followed the Ziegler–Nichols method for the most part. The altitude hold setpoint was hard-coded to be 10 Meters above the ground. All control surfaces have a deflection range of (-1,1). That said during normal flight they should never get close to the maximum ranges. When testing full elevator deflection in flight the plane immedietly turns 90 degrees and stalls.

4. FUZZY PID!

The altitudePID node works well for holding altidude while the wings are level, but an ubrupt bank will begin large altitude oscillations. I believe this is due to the amount verticle lift that the elevator can influence being decreased with larger bank angles. The PID controller was tuned for maximum lift influence, so it makes sense that it will have problems when it falls out its ideal environment. To fix this issue the gains of the PID controller need to be altered during operation.

I found a white paper that covers an implementation of fuzzy-inference for airplane pitch control [1]. Since pitch is controlled with the elevator position I believed it would also work as an altitude controller. I created the "fuzzy-altitudePID" node that takes the fuzzy logic rules presented in the paper and integrates them with the altitudePID node from earlier. While the rules where kept the same I changed the ranges of all other parameters. All of these values where found from experimentation. For instance, the error delta range was determined by sending large manual inputs to the plane in flight to see what maximum and minimum error values could be. The tuning method from the original altitudePID node did not work for the fuzzy ruleset.

I. code

Listing 1: altitudePID

```
#!/usr/bin/env python

import rospy
from rosflight_msgs.msg import Command, Barometer
from simple_pid import PID

altitude = None
altitudeSetpoint = 10

# create PID controller
pid = PID(0.0015,0.0004,0.003, setpoint=altitudeSetpoint)
pid.output_limits = (-1, 1) # Aileron

# Create Message Structure
msg = Command()
# need to ignore Aeileron, Rudder, and Throttle
msg.ignore = Command.IGNORE_X | Command.IGNORE_Z | Command.IGNORE_F
msg.mode = Command.MODE_PASS_THROUGH

# Create publisher
publisher = rospy.Publisher("/command",Command,queue_size=1)

# Recieves the altitude reading message and outputs elevator deflection commands
# Mapping of reading to command is done with a PID controller
def altitudeCallback(baro):
    altitude = baro.altitude
    pid.setpoint = altitudeSetpoint

    msg.header.stamp = rospy.Time.now()
    msg.y = pid(altitude)
    publisher.publish(msg)
    # Log info to console for Debugging
    rospy.loginfo("Altitude:"+str(altitude) + " Elevator:"+str(msg.y) )

if __name__ == '__main__':
    try:
        # Init Node
        rospy.init_node('altitudePID')

        # Create listener
        rospy.Subscriber("/baro",Barometer, altitudeCallback)

        rospy.spin()

    except rospy.ROSInterruptException:
        pass

#msg.x = 0.0 #Aeileron deflection (-1,1)
#msg.z = 0.0 #Rudder deflection (-1,1)
```

Listing 2: fuzzy-altitudePID

```
#!/usr/bin/env python

import rospy
from rosflight_msgs.msg import Command, Barometer
from simple_pid import PID
import numpy as np
import skfuzzy.control as ctrl
import time

```

```
altitude = None
altitudeSetpoint = 10

# create PID controller
pid = PID(0.0015,0.0004,0.003, setpoint=altitudeSetpoint) # PID tunings will be
    ↪ overwritten with fuzzy logic
pid.output_limits =(-1,1) # Maximum Elevator Deflections

# Time variables for calculating Error Delta
startTime=time.time()
endTime=0
lastPidError = 0

# Create Message Structure
msg = Command()
# need to ignore Aeileron, Rudder, and Throttle command outputs.
msg.ignore = Command.IGNORE_X | Command.IGNORE_Z | Command.IGNORE_F
msg.mode = Command.MODE_PASS_THROUGH

# Create publisher
publisher = rospy.Publisher("/command",Command,queue_size=1)

##########################
# Fuzzy Setup
##########################

# Create five fuzzy variables - two inputs, three outputs
error = ctrl.Antecedent(np.linspace(-5,5,7), 'error')
delta = ctrl.Antecedent(np.linspace(-40,40,7), 'delta')

"""
# Funtional
kp = ctrl.Consequent(np.linspace(0 ,0.00075,7), 'kp')
kd = ctrl.Consequent(np.linspace(0 ,0.0055,7), 'kd')
ki = ctrl.Consequent(np.linspace(0 ,0.00015,7), 'ki')
"""

# Experimental
kp = ctrl.Consequent(np.linspace(-0.000000,0.01,7), 'kp')
kd = ctrl.Consequent(np.linspace(-0.000000,0.02,7), 'kd')
ki = ctrl.Consequent(np.linspace(-0.000000,0.01,7), 'ki')

# Fuzzy Terms
names = ['nb', 'nm', 'ns', 'zo', 'ps', 'pm', 'pb']
error.automf(names=names)
delta.automf(names=names)
kp.automf(names=names)
ki.automf(names=names)
kd.automf(names=names)

# So many rules... here we go

# kp rules ################################################
rule0 = ctrl.Rule(antecedent=((error['nb'] & delta['nb']) |
                              (error['nm'] & delta['nb']) |
                              (error['nb'] & delta['nm']) |
                              (error['nm'] & delta['nm'])),
                  consequent=kp['pb'], label='rule kp pb')

rule1 = ctrl.Rule(antecedent=((error['ns'] & delta['nb']) |
                              (error['zo'] & delta['nb']) |
                              (error['ns'] & delta['nm']) |
```

```
                                (error['zo'] & delta['nm']) |
                                (error['nb'] & delta['ns']) |
                                (error['nm'] & delta['ns']) |
                                (error['ns'] & delta['ns']) |
                                (error['nb'] & delta['zo'])),
                    consequent=kp['pm'], label='rule kp pm')

rule2 = ctrl.Rule(antecedent=((error['ps'] & delta['nb']) |
                                (error['ps'] & delta['nm']) |
                                (error['zo'] & delta['ns']) |
                                (error['nm'] & delta['zo']) |
                                (error['ns'] & delta['zo']) |
                                (error['nb'] & delta['ps']) |
                                (error['nm'] & delta['ps']) |
                                (error['nb'] & delta['pm'])),
                    consequent=kp['ps'], label='rule kp ps')

rule3 = ctrl.Rule(antecedent=((error['pm'] & delta['nb']) |
                                (error['pb'] & delta['nb']) |
                                (error['pm'] & delta['nm']) |
                                (error['ps'] & delta['ns']) |
                                (error['zo'] & delta['zo']) |
                                (error['ns'] & delta['ps']) |
                                (error['nm'] & delta['pm']) |
                                (error['nb'] & delta['pb'])),
                    consequent=kp['zo'], label='rule kp zo')

rule4 = ctrl.Rule(antecedent=((error['pb'] & delta['nm']) |
                                (error['pm'] & delta['ns']) |
                                (error['ps'] & delta['zo']) |
                                (error['zo'] & delta['ps']) |
                                (error['ps'] & delta['ps']) |
                                (error['ns'] & delta['pm']) |
                                (error['nm'] & delta['pb'])),
                    consequent=kp['ns'], label='rule kp ns')

rule5 = ctrl.Rule(antecedent=((error['pb'] & delta['ns']) |
                                (error['pm'] & delta['zo']) |
                                (error['pb'] & delta['zo']) |
                                (error['pm'] & delta['ps']) |
                                (error['pb'] & delta['ps']) |
                                (error['pm'] & delta['pm']) |
                                (error['ps'] & delta['pm']) |
                                (error['zo'] & delta['pm']) |
                                (error['ns'] & delta['pb']) |
                                (error['zo'] & delta['pb']) |
                                (error['ps'] & delta['pb'])),
                    consequent=kp['nm'], label='rule kp nm')

rule6 = ctrl.Rule(antecedent=((error['pb'] & delta['pm']) |
                                (error['pm'] & delta['pb']) |
                                (error['pb'] & delta['pb'])),
                    consequent=kp['nb'], label='rule kp nb')

# ki rules #################################################
rule7 = ctrl.Rule(antecedent=((error['nb'] & delta['nb']) |
                                (error['nm'] & delta['nb']) |
                                (error['ns'] & delta['nb']) |
                                (error['nb'] & delta['nm']) |
                                (error['nm'] & delta['nm']) |
                                (error['nb'] & delta['ns'])),
                    consequent=ki['nb'], label='rule ki nb')
```

```
133
134 rule8 = ctrl.Rule(antecedent=((error['zo'] & delta['nb']) |
135                            (error['ns'] & delta['nm']) |
136                            (error['nm'] & delta['ns']) |
137                            (error['nb'] & delta['zo'])),
138                    consequent=ki['nm'], label='rule ki nm')
139
140 rule9 = ctrl.Rule(antecedent=((error['ps'] & delta['nb']) |
141                            (error['zo'] & delta['nm']) |
142                            (error['ps'] & delta['nm']) |
143                            (error['ns'] & delta['ns']) |
144                            (error['zo'] & delta['ns']) |
145                            (error['nm'] & delta['zo']) |
146                            (error['ns'] & delta['zo']) |
147                            (error['nm'] & delta['ps']) |
148                            (error['nb'] & delta['ps'])),
149                    consequent=ki['ns'], label='rule ki ns')
150
151 rule10 = ctrl.Rule(antecedent=((error['pm'] & delta['nb']) |
152                            (error['pb'] & delta['nb']) |
153                            (error['pm'] & delta['nm']) |
154                            (error['pb'] & delta['nm']) |
155                            (error['ps'] & delta['ns']) |
156                            (error['zo'] & delta['zo']) |
157                            (error['ns'] & delta['ps']) |
158                            (error['nm'] & delta['pm']) |
159                            (error['nb'] & delta['pm']) |
160                            (error['nm'] & delta['pb']) |
161                            (error['nb'] & delta['pb'])),
162                    consequent=ki['zo'], label='rule ki zo')
163
164 rule11 = ctrl.Rule(antecedent=((error['pm'] & delta['ns']) |
165                            (error['pb'] & delta['ns']) |
166                            (error['ps'] & delta['zo']) |
167                            (error['pm'] & delta['zo']) |
168                            (error['zo'] & delta['ps']) |
169                            (error['ps'] & delta['ps']) |
170                            (error['ns'] & delta['pm']) |
171                            (error['ns'] & delta['pb'])),
172                    consequent=ki['ps'], label='rule ki ps')
173
174 rule12 = ctrl.Rule(antecedent=((error['pb'] & delta['zo']) |
175                            (error['pm'] & delta['ps']) |
176                            (error['ps'] & delta['pm']) |
177                            (error['zo'] & delta['pm']) |
178                            (error['zo'] & delta['pb'])),
179                    consequent=ki['pm'], label='rule ki pm')
180
181 rule13 = ctrl.Rule(antecedent=((error['pb'] & delta['ps']) |
182                            (error['pm'] & delta['pm']) |
183                            (error['pb'] & delta['pm']) |
184                            (error['pb'] & delta['pb']) |
185                            (error['pm'] & delta['pb']) |
186                            (error['ps'] & delta['pb'])),
187                    consequent=ki['pb'], label='rule ki pb')
188
189 # kd rules ################################################
190 rule14 = ctrl.Rule(antecedent=((error['nb'] & delta['ns']) |
191                            (error['nm'] & delta['ns']) |
192                            (error['nb'] & delta['zo']) |
193                            (error['nb'] & delta['ps'])),
194                    consequent=kd['nb'], label='rule kd nb')
```

```
195
196 rule15 = ctrl.Rule(antecedent=((error['nb'] & delta['nm']) |
197                                 (error['ns'] & delta['ns']) |
198                                 (error['nm'] & delta['zo']) |
199                                 (error['ns'] & delta['zo']) |
200                                 (error['nm'] & delta['ps']) |
201                                 (error['nb'] & delta['pm'])),
202                     consequent=kd['nm'], label='rule kd nm')
203
204 rule16 = ctrl.Rule(antecedent=((error['nm'] & delta['nm']) |
205                                 (error['ns'] & delta['nm']) |
206                                 (error['zo'] & delta['nm']) |
207                                 (error['ps'] & delta['nm']) |
208                                 (error['pm'] & delta['nm']) |
209                                 (error['zo'] & delta['ns']) |
210                                 (error['zo'] & delta['zo']) |
211                                 (error['zo'] & delta['ps']) |
212                                 (error['ns'] & delta['ps']) |
213                                 (error['zo'] & delta['pm']) |
214                                 (error['ns'] & delta['pm']) |
215                                 (error['nm'] & delta['pm'])),
216                                 #(error['nb'] & delta['pb']) | Test this change , and
                                        ↪ remove from 'rule kd ps'
217                                 #(error['nm'] & delta['pb']) |
218                     consequent=kd['ns'], label='rule kd ns')
219
220 rule17 = ctrl.Rule(antecedent=((error['ns'] & delta['nb']) |
221                                 (error['zo'] & delta['nb']) |
222                                 (error['ps'] & delta['nb']) |
223                                 (error['ps'] & delta['ns']) |
224                                 (error['ps'] & delta['zo']) |
225                                 (error['ps'] & delta['ps']) |
226                                 (error['ps'] & delta['pm']) |
227                                 (error['zo'] & delta['pb']) |
228                                 (error['ns'] & delta['pb'])),
229                     consequent=kd['zo'], label='rule kd zo')
230
231 rule18 = ctrl.Rule(antecedent=((error['nb'] & delta['nb']) |
232                                 (error['nm'] & delta['nb']) |
233                                 (error['pm'] & delta['ns']) |
234                                 (error['pm'] & delta['zo']) |
235                                 (error['pm'] & delta['ps']) |
236                                 (error['pb'] & delta['ps']) |
237                                 (error['pm'] & delta['pm']) |
238                                 (error['pb'] & delta['pm']) |
239                                 (error['nb'] & delta['pb']) | # Really? I'm thinkin delta
                                        ↪ is 'ns' instead
240                                 (error['nm'] & delta['pb']) | # Really? I'm thinkin delta
                                        ↪ is 'ns' instead
241                                 (error['ps'] & delta['pb'])),
242                     consequent=kd['ps'], label='rule kd ps')
243
244 rule19 = ctrl.Rule(antecedent=((error['pb'] & delta['nm']) |
245                                 (error['pb'] & delta['ns']) |
246                                 (error['pb'] & delta['zo'])),
247                     consequent=kd['pm'], label='rule kd pm')
248
249 rule20 = ctrl.Rule(antecedent=((error['pm'] & delta['nb']) |
250                                 (error['pb'] & delta['nb']) |
251                                 (error['pm'] & delta['pb']) |
252                                 (error['pb'] & delta['pb'])),
253                     consequent=kd['pb'], label='rule kd pb')
```

```
254
255 system = ctrl.ControlSystem(rules=[
256                                  rule0, rule1, rule2, rule3, rule4, rule5, rule6
                                     ↪ ,
257                                  rule7, rule8, rule9, rule10, rule11, rule12,
                                     ↪ rule13,
258                                  rule14, rule15, rule16, rule17, rule18, rule19,
                                     ↪ rule20
259                                  ])
260 sim = ctrl.ControlSystemSimulation(system, flush_after_run=1000) # lower flush if memory
    ↪ is scarce
261
262 altList=[]
263 # Averages the last three altimeter readings before sending the reading to altitudePID
264 # Currently not used!
265 def altimeterFilter(baro):
266     altList.insert(0,baro.altitude)
267     if len(altList) > 3:
268         altList.pop()
269         avgAltitude = sum(altList) / float(len(altList))
270         altitudePID(avgAltitude)
271
272 # Recieves altitude readings and outputs Elevator deflection commands
273 def altitudePID(baro):
274     altitude = baro.altitude
275
276     global startTime
277     global endTime
278     global lastPidError
279     pid.setpoint = altitudeSetpoint
280
281     # Get error and delta
282     pidError= altitudeSetpoint - altitude
283     pidDelta = float(pidError - lastPidError)/float(endTime - startTime)
284     lastPidError = pidError
285
286     # Reset timer for calculating error delta
287     endTime = startTime
288     startTime = time.time()
289
290     # Compute Fuzzy Inference
291     sim.input['error']= pidError
292     sim.input['delta']= pidDelta
293     sim.compute()
294
295     #Set pid tunings from fuzzy logic
296     pid.tunings = (sim.output['kp'],
297                    sim.output['ki'],
298                    sim.output['kd']
299                    )
300
301     msg.header.stamp = rospy.Time.now()
302     msg.y = pid(altitude)
303     publisher.publish(msg)
304     # Send info to the console for debugging
305     rospy.loginfo("Altitude:"+str(round(altitude, 4)) +
306                   " Elevator:"+str(round(msg.y, 4)) +
307                   " Kp:"+str(round(sim.output['kp'], 4)) +
308                   " Ki:"+str(round(sim.output['ki'], 4)) +
309                   " Kd:"+str(round(sim.output['kd'], 4)) +
310                   " Error:"+str(round(pidError)) +
311                   " Delta:"+str(round(pidDelta))
```

```
312                         )
313
314 if __name__ == '__main__':
315     try:
316         # Init Node
317         rospy.init_node('fuzzy-altitudePID')
318
319         # Create listener
320         #rospy.Subscriber("/baro",Barometer, altimeterFilter) # with filter
321         rospy.Subscriber("/baro",Barometer, altitudePID ) # bypass filter
322
323         rospy.spin()
324
325     except rospy.ROSInterruptException:
326         pass
327
328 #msg.x = 0.0 #Aeileron deflection (-1,1)
329 #msg.z = 0.0 #Rudder deflection (-1,1)
```

REFERENCES

[1] N. Beygi, M. Beigy, and M. Siahi, "Design of fuzzy self-tuning pid controller for pitch control system of aircraft autopilot," 2015. [Online]. Available: https://arxiv.org/abs/1510.02588