Processor in the Loop Simulation Guide

UAV Research Group
University of Minnesota, Twin Cities

This document describes how to run the UMN UAV Processor in the Loop (PIL) simulation whose main goal is to verify the proper operation of the flight software before flight testing. This is achieved by running the flight computer in the loop with the nonlinear UAV simulation. A schematic of the current setup is presented as follows:

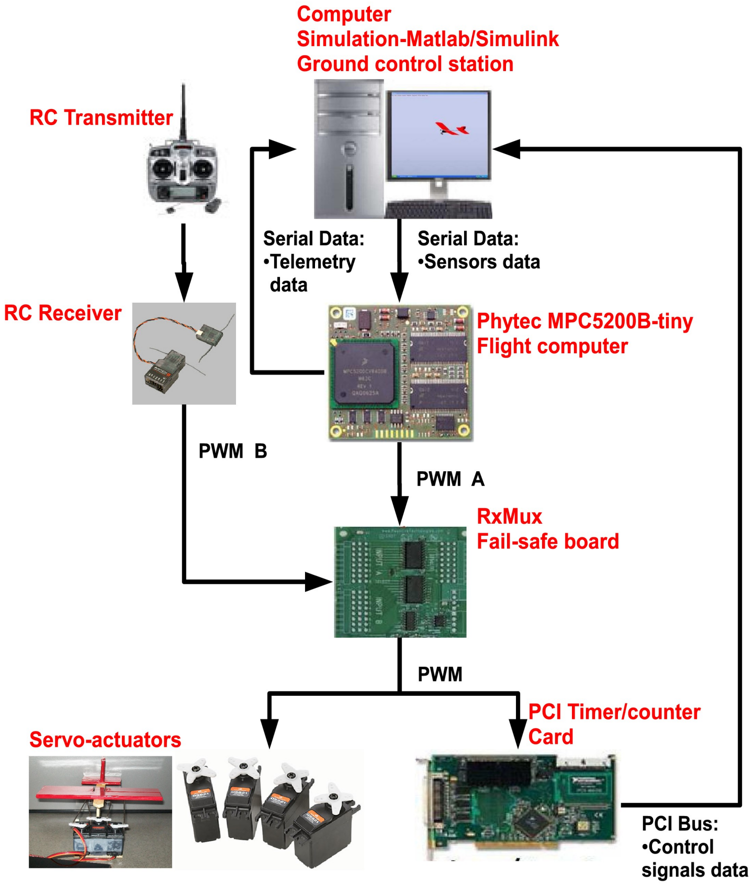


Figure 1. Processor in the loop layout

Overall System Description:

The connection of the overall system is depicted in Figure 1. The simulation computer simulates the UAV dynamics and transmits sensor values through the serial port of the computer to the flight computer (MPC5200b-tiny). The flight computer reads the sensor inputs and generates a set of actuator commands (elevator, aileron, rudder and throttle). These commands are translated to PWM (Pulse Width Modulated) signals that can be also generated by the manual pilot if manual mode is selected in the transmitter. The timer counter card reads the PWM signals which are used by the simulation as inputs to the UAV model. This model is executed in real time on Matlab/Simulink using Real Time

Windows Target. The hardware setup is shown in Figure 2.

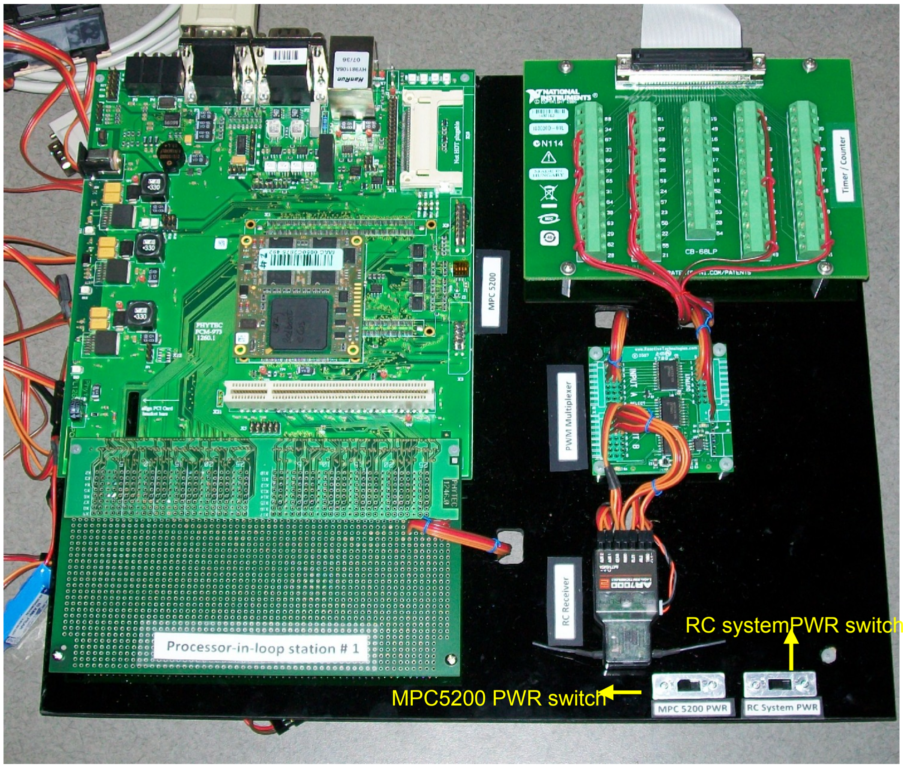


Figure 2. Hardware setup

Components Description

Flight computer and development board: The Phytec-MPC5200b-tiny is a single board computer where the control, navigation and data acquisition algorithms are executed. Figure 3 shows this device:

Figure 3. phyCORE-MPC5200B-tiny System on module

This board is plugged into the daughter board of the UAV during flight testing. For the processor in the loop simulation, the board is mounted on the development board shown in Figure 4.

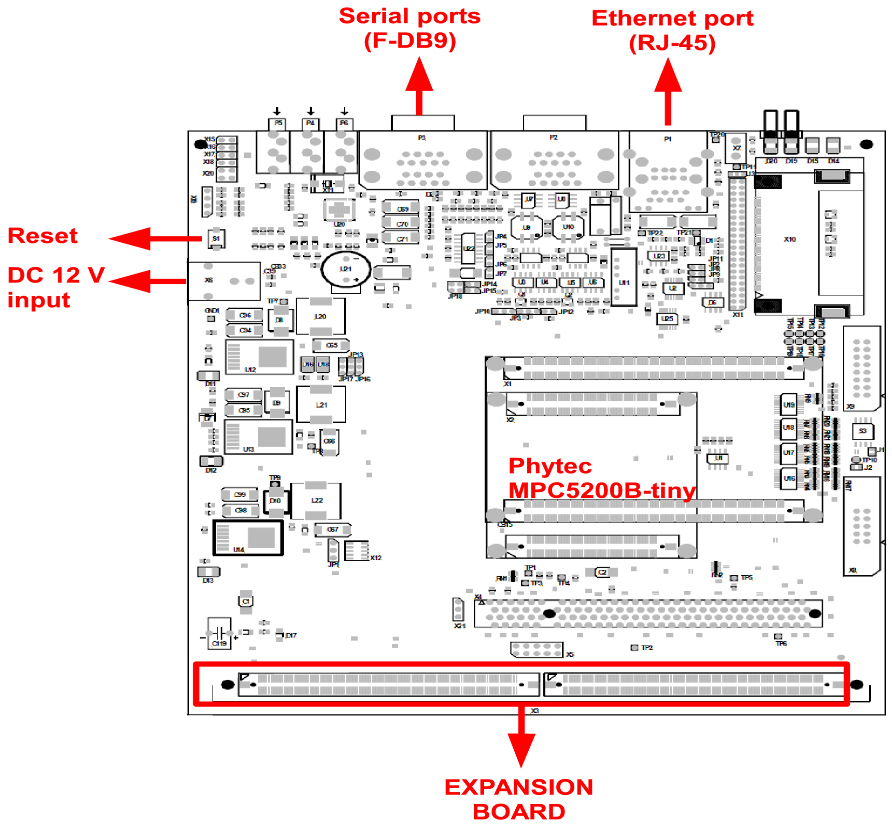


Figure 4. Development board for MPC5200B-tiny

The development board connects all the input and output ports of the MPC5200b-tiny to external connectors and hardware interfaces.

RxMux: PWM signal multiplexer used to switch between the flight computer and manual pilot commands.

Timer counter card: National instruments PCI-6602 is a card that reads the PWM signals sent by the computer or the manual pilot. These signals are used by the simulation as control commands for the UAV model.

Simulation computer: This computer is used to run the simulation software and hosts the development tools required to compile and load the flight code onto the embedded system.

RC receiver and transmitter: The RC transmitter sends pilot commands to the receiver. The receiver converts these commands to PWM signals which are read by the actuators and the timer counter card.

Servo actuators: Rotational actuators read a reference PWM signal to set their angular positions. This actuators allow visualization of transmitted commands from either the flight computer or the manual pilot.

System interconnection:

A list of hardware interconnections is given as follows:

- Serial port 1 of the development board (Top Female-DB9 port) connected to serial port 1 of the computer (COM1)
- Serial port 2 of the development board (Bottom Female-DB9 port) connected to serial port 2 of the computer (COM2).
- Ethernet cable connected to either the network or the computer. **Note: If the development board is connected directly to the computer a crossover Ethernet cable is necessary.** The network option is recommended.
- Ribbon cable between computer and Timer counter card

Software Description:

Simulation Software:

The following software has been installed in the computers located in the UAV Laboratory.

Operating System: 32 bits Windows XP is used because of performance and compatibility with Real-Time Windows Target.

Matlab/Simulink R2010a: A 32 bits Matlab/Simulink version 2010a is required to run the UMN UAV simulation. These models also require the following toolboxes:

- Simulink Control Design
- Real Time Windows Target,
- Aerospace Toolbox
- The Aerospace Blockset,

FlightGear: Shows the simulation outputs using a 3D model of an aircraft.

OpenUGS Ground Station: Utilized to display navigation solutions, states and status computed by the flight computer. Furthermore, it can be used as a serial terminal to access the embedded system (flight computer).

Development Software:

The following software has been installed in the computers located in the UAV Laboratory.

TFTP server: Tftp-32 software is used to transfer data between the PC and the flight computer through the network by using TFTP protocol

Terminal: Either Hyperterminal or any other serial terminal program can be used to communicate with the embedded system. To avoid the use of several programs during the simulation and software development, the OpenUGS ground station enables serial communication.

Cygwin: A GNU/Linux emulator used to compile the flight software for the MPC5200 single board computer.

cCos (Embedded configurable operating system) version 3.0: The eCos development tools for power-pc as well as the libraries and utilities for the MPC5200 single board computer must be installed on the development computer in order to compile the flight software. Computers located in the laboratory have the eCos tools already installed.

Procedure for Running PIL Simulation

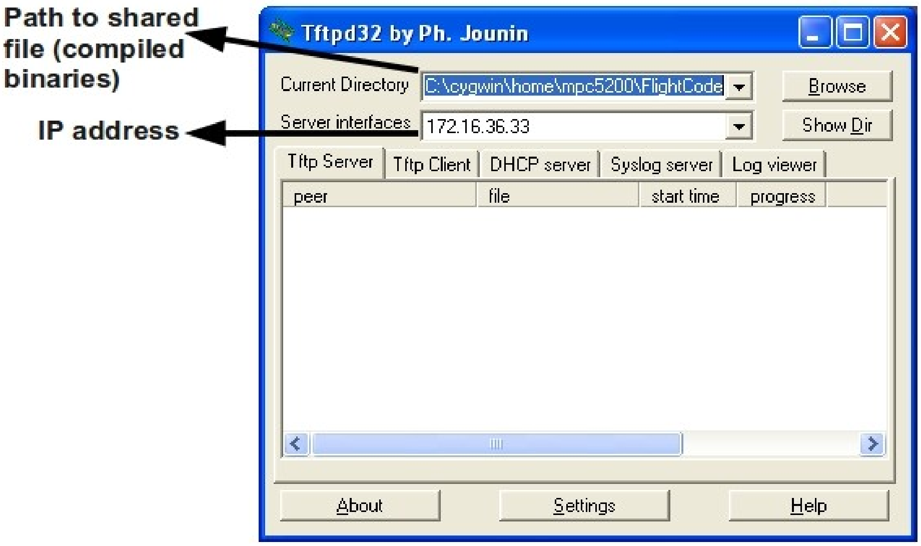
Follow the steps below to run the processor in the loop simulation:

Running the simulation models:

Go to the folder *Simulation/PIL_Sim* and execute the Matlab script "setup.m" to start the simulation and external programs (Ground Station and FlightGear). This script sets the aircraft configuration and trim condition by loading two files from the *Libraries* directory, 'UAV_modelconfig.mat' and 'UAV_trimcondition.mat'. The sample time of the simulation and the flight software is set in this script, as is the value of the time delay in the flight control loop. The serial communication MEX-file is compiled, and the RTW target is built and connected. At this point, the simulation is ready to run.

Loading the embedded program:

- Start the TFTP server tftp-32 from the desktop icon or the programs menu. Then, select the folder where the MPC5200 binary files will be located. Usually this is the same source code directory (*Software/FlightCode*).



Current Directory: C:\cygwin\home\mpc5200\FlightCode

Server interfaces: 172.16.36.33

Figure 5. Tftpd32 window

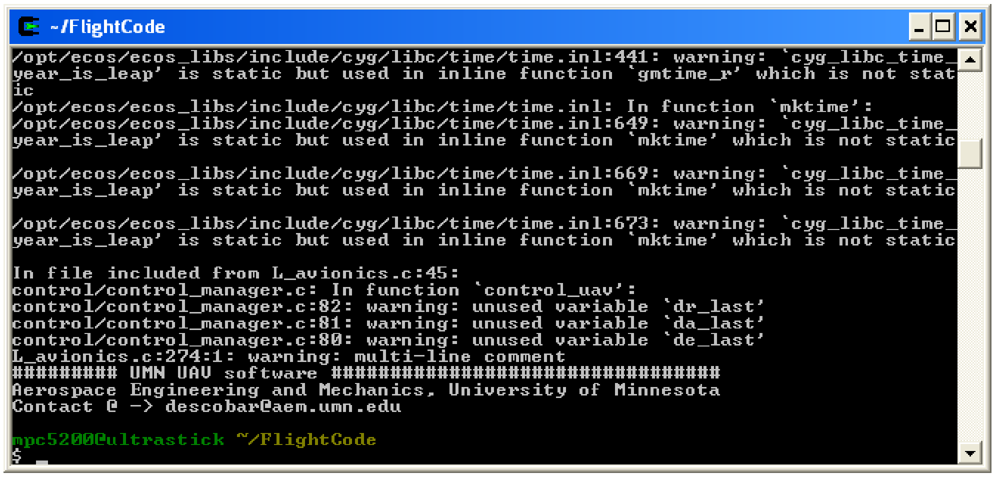
- Compile the flight code:

- Edit the file *Software/FlightCode/Makefile to* change the selected flight controller:. To specify which controller will be compiled modify line 40, which is as follows:

```
OBJ = L_avionics.c control/baseline_control.c
```

With this code, the controller in "Software/FlightCode/control/baseline_control.c" will be compiled. This code is the same code used in the Software in the Loop simulation (SIL).

- Start Cygwin, and change to the directory where the source code is located. It can be done by using the "cd" command. For example "cd <base_dir>/Software/FlightCode"
- Type "make" in the Cygwin terminal. If no compilation errors are displayed, the binary file called "output" will be generated. This file is an executable which will be loaded onto the MPC5200b-tiny - flight computer. Recall that this file must be placed in the folder selected for the TFTP server operation. To remove all the files generated from the compilation type: *make clean.*



```
/opt/ecos/ecos_libs/include/cyg/libc/time/time.inl:441: warning: `cyg_libc_time_
year_is_leap' is static but used in inline function `gmtime_r' which is not stat
ic
/opt/ecos/ecos_libs/include/cyg/libc/time/time.inl: In function `mktime':
/opt/ecos/ecos_libs/include/cyg/libc/time/time.inl:649: warning: `cyg_libc_time_
year_is_leap' is static but used in inline function `mktime' which is not static

/opt/ecos/ecos_libs/include/cyg/libc/time/time.inl:669: warning: `cyg_libc_time_
year_is_leap' is static but used in inline function `mktime' which is not static

/opt/ecos/ecos_libs/include/cyg/libc/time/time.inl:673: warning: `cyg_libc_time_
year_is_leap' is static but used in inline function `mktime' which is not static

In file included from L_avionics.c:45:
control/control_manager.c: In function `control_uav':
control/control_manager.c:82: warning: unused variable `dr_last'
control/control_manager.c:81: warning: unused variable `da_last'
control/control_manager.c:80: warning: unused variable `de_last'
L_avionics.c:274:1: warning: multi-line comment
######### UMN UAV software #################################
Aerospace Engineering and Mechanics, University of Minnesota
Contact @ -> descobar@aem.umn.edu

mpc5200@ultrastick ~/FlightCode
$ _
```

Figure 6. Cygwin terminal

- Load executable file onto flight computer:
  - If not started, run the OpenUGS ground station software from the desktop icon or the executable file.

  - Click on the "Settings" tab, then make sure the following parameters are in place
    - Port name: COM2
    - Bit rate: 115200
    - Data bits: 8
    - Stop bits: 1
    - Parity: none
    - Flow control: none
    - Interface: Terminal
    - Mode: ASCII
  - Click on *Options – Input – Serial port*. The console at the button should display the message "Serial communication initialized !". A screen shot of the Ground Station program is shown

in Figure 7.

- Turn on all the electronics by following the steps below:
  - Turn on the power supply
  - Turn on the switch labeled as “RC system PWR”
  - Turn on the switch labeled as “MPC5200 PWR”
- Once the flight computer is on, the serial terminal should display *RedBoot>*. For loading the binary file located in the host computer type the command as follows:

  ```
  load -m tftp -h <pc_ip_address> output
  ```

  <pc_ip_address> is the IP address of the computer where the binary file is located and the TFTP server is running. The ip address can be found out in the Tftpd32 window as shown in Figure 5. After executing the previous line the terminal should display something similar to:

  ```
  ***Loadable segment: 0, Len=479368

  Entry point: 0x00100100, address range: 0x00100000-0x00175088

  RedBoot>
  ```

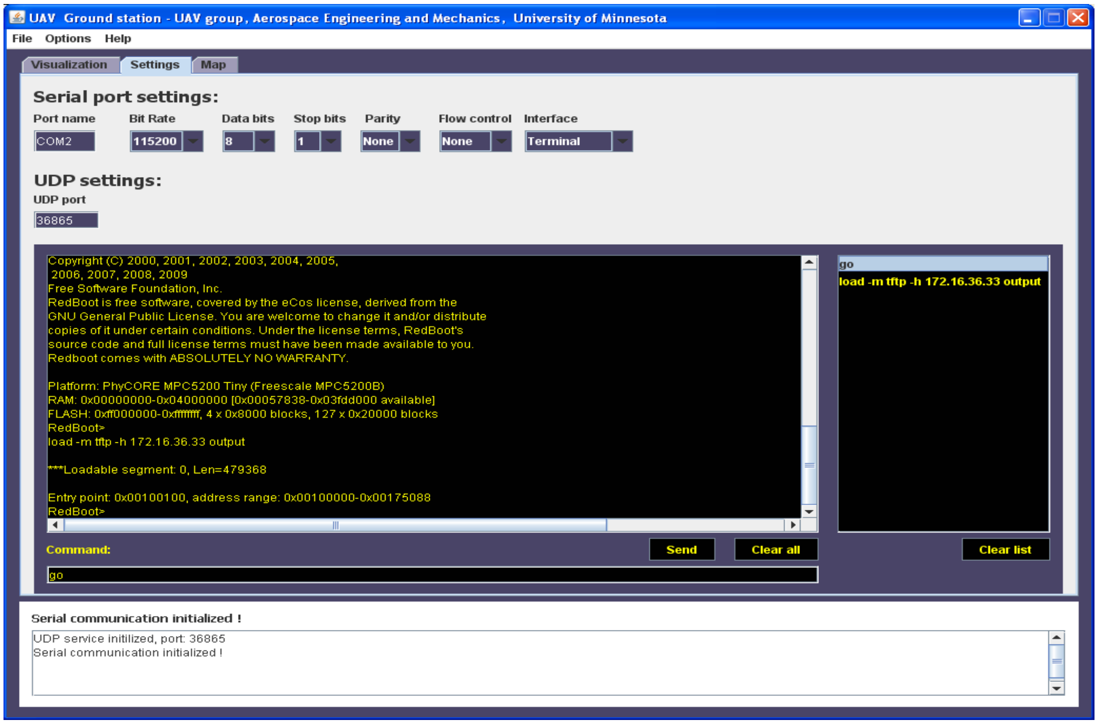
Once the binary file is loaded in RAM memory, you are be able to run the embedded program by typing *go.*

If you want to save the binary file in a non volatile memory (flash memory) type the following command.

```
fis create output
```

To load this program from flash memory type:

```
fis load output
```



UAV Ground station - UAV group, Aerospace Engineering and Mechanics, University of Minnesota
File
Options
Help
Visualization
Settings
Map
Send
Clear all
Clear list

Serial port settings:

Port name: COM2
Bit Rate: 115200
Data bits: 8
Stop bits: 1
Parity: None
Flow control: None
Interface: Terminal

UDP settings:

UDP port: 36865

```
Copyright (C) 2000, 2001, 2002, 2003, 2004, 2005,
 2006, 2007, 2008, 2009
Free Software Foundation, Inc.
RedBoot is free software, covered by the eCos license, derived from the
GNU General Public License. You are welcome to change it and/or distribute
copies of it under certain conditions. Under the license terms, RedBoot's
source code and full license terms must have been made available to you.
Redboot comes with ABSOLUTELY NO WARRANTY.

Platform: PhyCORE MPC5200 Tiny (Freescale MPC5200B)
RAM: 0x00000000-0x04000000 [0x00057838-0x03fdd000 available]
FLASH: 0xff000000-0xffffffff, 4 x 0x8000 blocks, 127 x 0x20000 blocks
RedBoot>
load -m tftp -h 172.16.36.33 output

***Loadable segment: 0, Len=479368

Entry point: 0x00100100, address range: 0x00100000-0x00175088
RedBoot>
```

```
go
load -m tftp -h 172.16.36.33 output
```

Command: go

Serial communication initialized !

```
UDP service initilized, port: 36865
Serial communication initialized !
```

Figure 7. OpenUGS Ground station terminal

- Turn on the transmitter using the *turn on/off switch* shown in Figure 8. Then, change to autopilot mode by switching the *gear switch* from 1 to 0. The positions 0 and 1 are labeled in the right side of the gear switch.

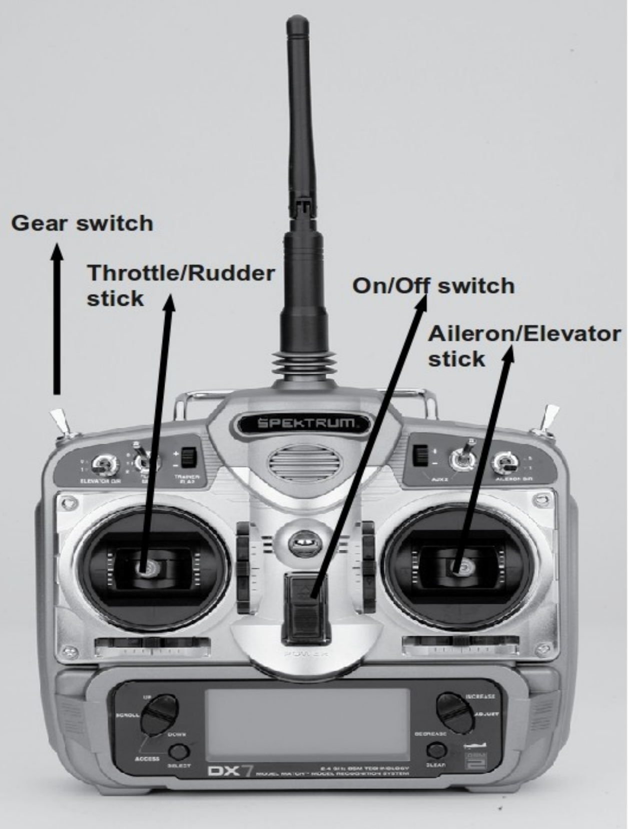
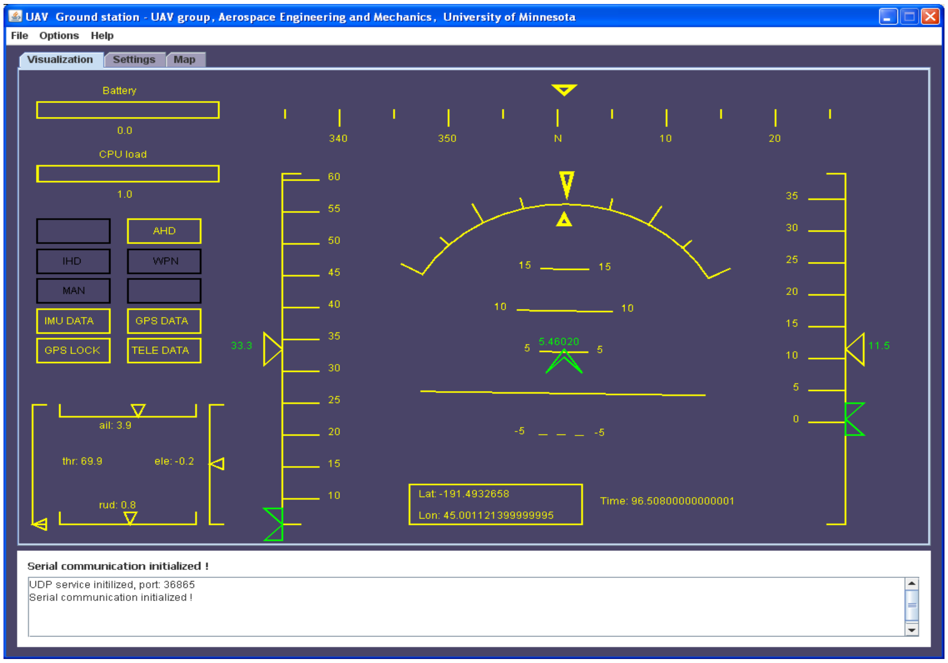


Figure 8. R/C Transmitter

- Before running the flight computer program, make sure you have started the simulation. During 10 seconds the simulation will retain the trim conditions. You should start the flight computer in that period of time.
- To start the flight computer program type the command *go* in the serial terminal. To visualize the flight computer program output in the ground station change the interface box from Terminal to visualization, and click on the Visualization tab.
- At this point, the autopilot should take control of the UAV model, and you can see the behavior of the system by looking at the Ground station and FlightGear. The Ground station displays the state solutions from the flight computer while FlightGear displays the simulation solutions. Figure 8 shows the Ground station - visualization tab.



Battery: 0.0

CPU load: 1.0

33.3

5.46020

11.5

ail: 3.9

thr: 69.9

ele: -0.2

rud: 0.8

Lat: -191.4932658

Lon: 45.001121399999995

Time: 96.50800000000001

Serial communication initialized !

```
UDP service initilized, port: 36865
Serial communication initialized !
```

Figure 9. OpenUGS Ground station – Visualization tab