Middle East Technical University
Department of Aerospace Engineering

MSc Thesis Presentation

INTERFACING SIMULINK/MATLAB WITH V-REP FOR ANALYSIS AND CONTROL SYNTHESIS OF A QUADROTOR

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Motivation

- The design and implementation of control algorithms is not fast implantable always due to lack of physical test flights.
- Limit on indoor flights and mapping algorithm design due to lack of 2D and 3D vision sensor.
- Limit on swarm algorithms due to cost and again lack of custom sensors.
- To test model and implement controller algorithms and observe 3-D physical interaction, Simulink/Matlab is interfaced with V-REP directly.

Introduction

- The quadrotor is a Vertical Takeoff and Landing (VTOL) rotorcraft which is propelled by four fixed or variable pitch rotor.
- The use of area of quadrotors include military applications such as border patrolling, cartography, cost guards and also civilian applications such as mapping, search and rescue missions, agricultural applications, power and nuclear plants inspection and etc.
- The propellers used in quadrotor in our study are fixed pitch propellers, so the control of quadrotor is done by changing the rotation speed of propellers. The front and rear propeller are rotating clockwise and the left and right propellers are rotating counter clockwise.

Mathematical Model

- The relation between thrust and rotational speed is as follows,

$$T = c_T \omega^2$$

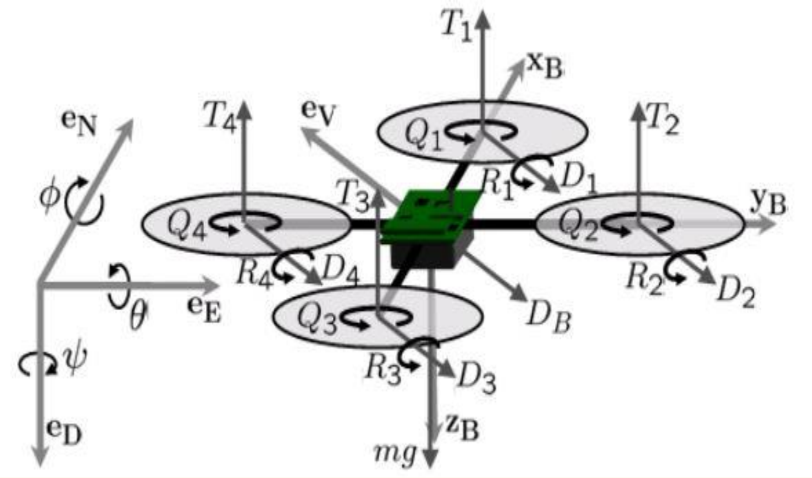
where c_T is motor-prop specified thrust constant. The relation between propeller torque and rotational speed is as follows,

$$Q = c_Q \omega^2$$

- The four controller inputs for quadrotor control are as follows:

$$U_1 = T_1 + T_2 + T_3 + T_4$$
$$U_2 = T_4 - T_2$$
$$U_3 = T_3 - T_1$$
$$U_4 = Q_2 + Q_4 - Q_1 - Q_3$$

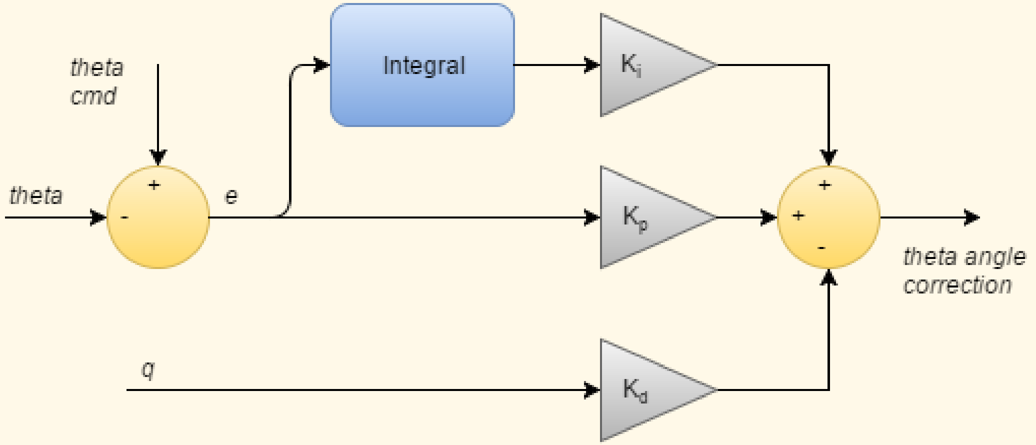
The units of U_1,U_2 and U_3 are N, where the unit of U_4 is Nm



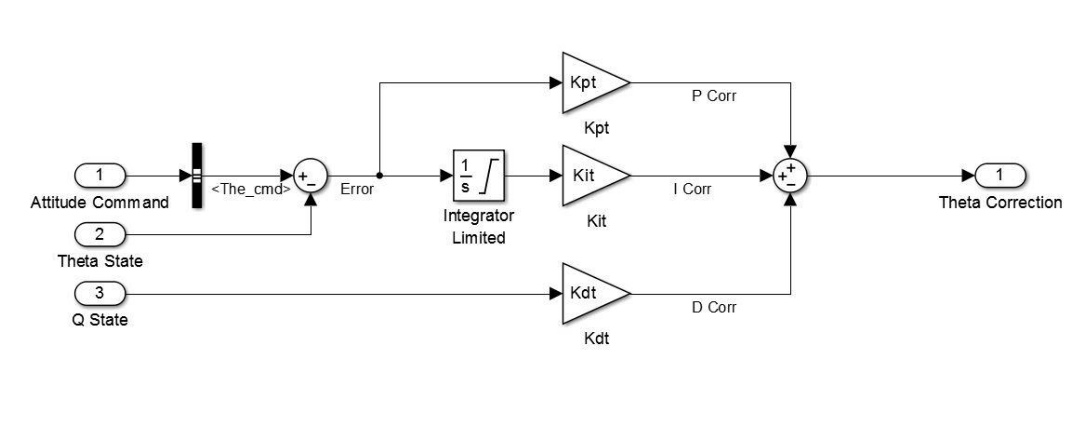
Controller Design

- The roll, pitch, and altitude hold controller is designed
- Classical PID control is selected as the control method
- The mathematical model and controller were implemented in Simulink/Matlab

Gains	Hover	Roll Angle	Pitch
K_p	16	25	25
K_i	1	0	0
K_d	10	6	6



Pitch Controller Schematic and Simulink Implementation



Quadrotor Specifications

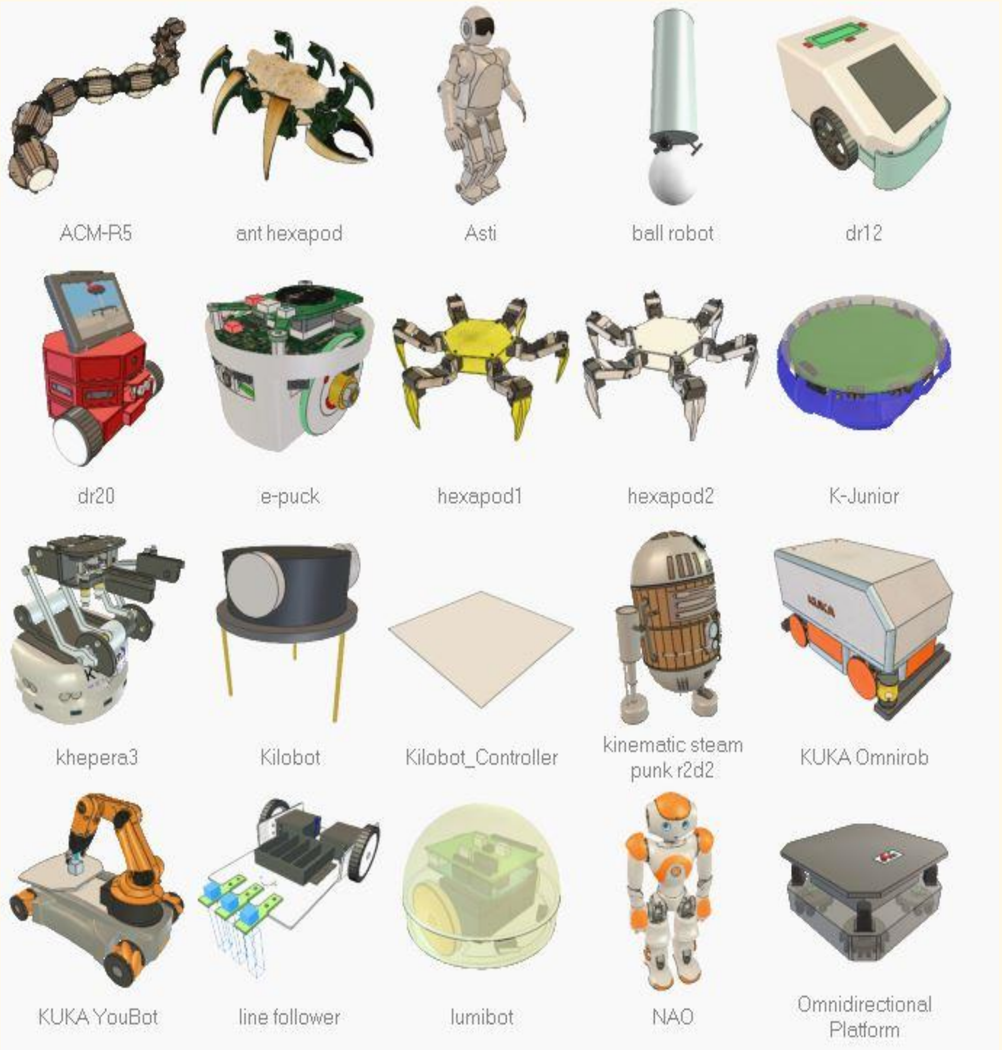
Model	AscTec Hummingbird
Manufacturer	Ascending Technologies GmbH
Takeoff weight (2100 mAh TP battery)	480 g
Distance between motor axes	34 cm
Flight control and IMU board	AscTec Autopilot
Propeller	8” flexible standard propeller grey
Motors	AscTec X-BL 52s
Motor controller	AscTec X-BLDC
Thrust per Motor (standard propeller)	0,05 – 3,5 N
Radio control system	Futaba Fasst 2,4 GHz
Telemetry System	Xbee 2,4 GHz
Moment of inertia	$I_{xx} = I_{yy} = 5{,}6 \cdot 10^{-3}$ kg*m; $I_{zz} = 8{,}1 \cdot 10^{-3}$ kg*m

Quadrotor Specifications

- The main frame of quadrotor is made out of sandwich material consisting of carbon fiber and balsa wood.
- The system has a pressure sensor, three axis compass, GPS unit, an acceleration sensor, and three gyroscopes (one for each axis).
- AscTec Autopilot main board consist of two ARM 7 60MHz, 32 Bit microcontrollers – a low level processor (LLP) and a high level processor (HLP).
- LLP collects IMU (accelerometer + gyroscopes) data, sends commands to the motor controller and is responsible from attitude control of quadrotor.
- The HLP controls the GPS and free for user defined control algorithm designs.
- The control algorithms can be designed in Simulink/Matlab environment, the control system is then translated to the C code by the Real Time Workshop Embedded coder.
- The communication of AscTec Hummingbird with ground is provided by a wireless Xbee model via serial port.

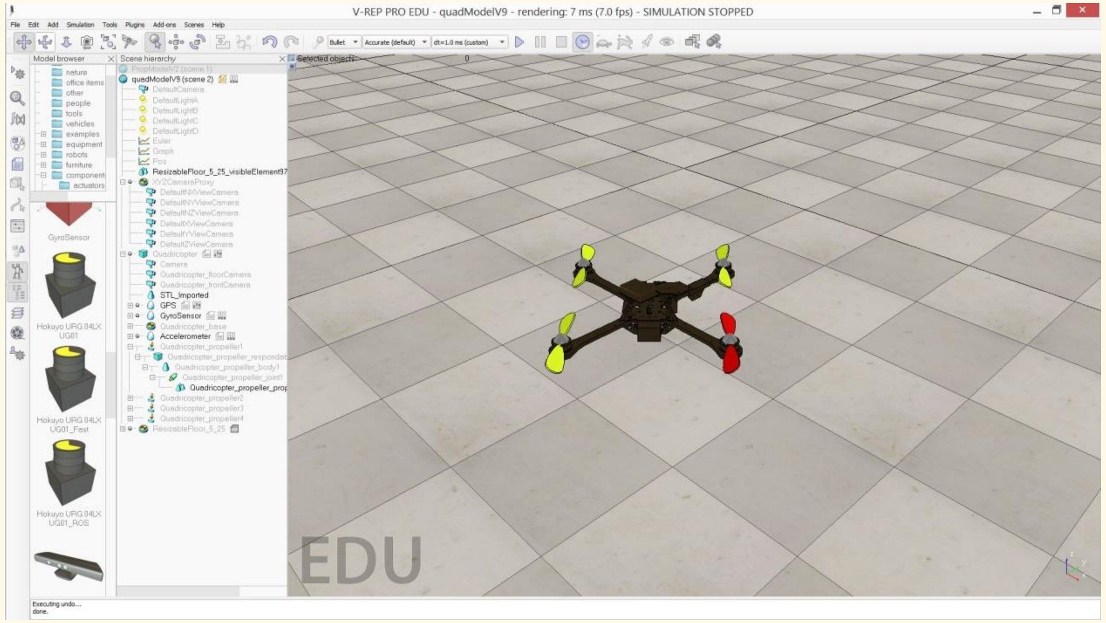
Virtual Robot Experimentation Platform (V-REP)

- Virtual Robot Experimental Platform (V-REP) is the product of Coppelia Robotics that developed for general purpose robot simulation.
- During the active simulation this area acts as real 3D world and gives real time feedback according to the behavior of models.
- There is a wide sensor and robot model library in V-REP environment
- The main internal control mechanism is the use of threaded and non-threaded child scripts in Lua language
- For simulator-in-the-loop configuration tests V-REP offers also a method to control the simulation from outside the simulator by external implied controller algorithm in C/C++, Python, Java, Matlab or Urbi languages.

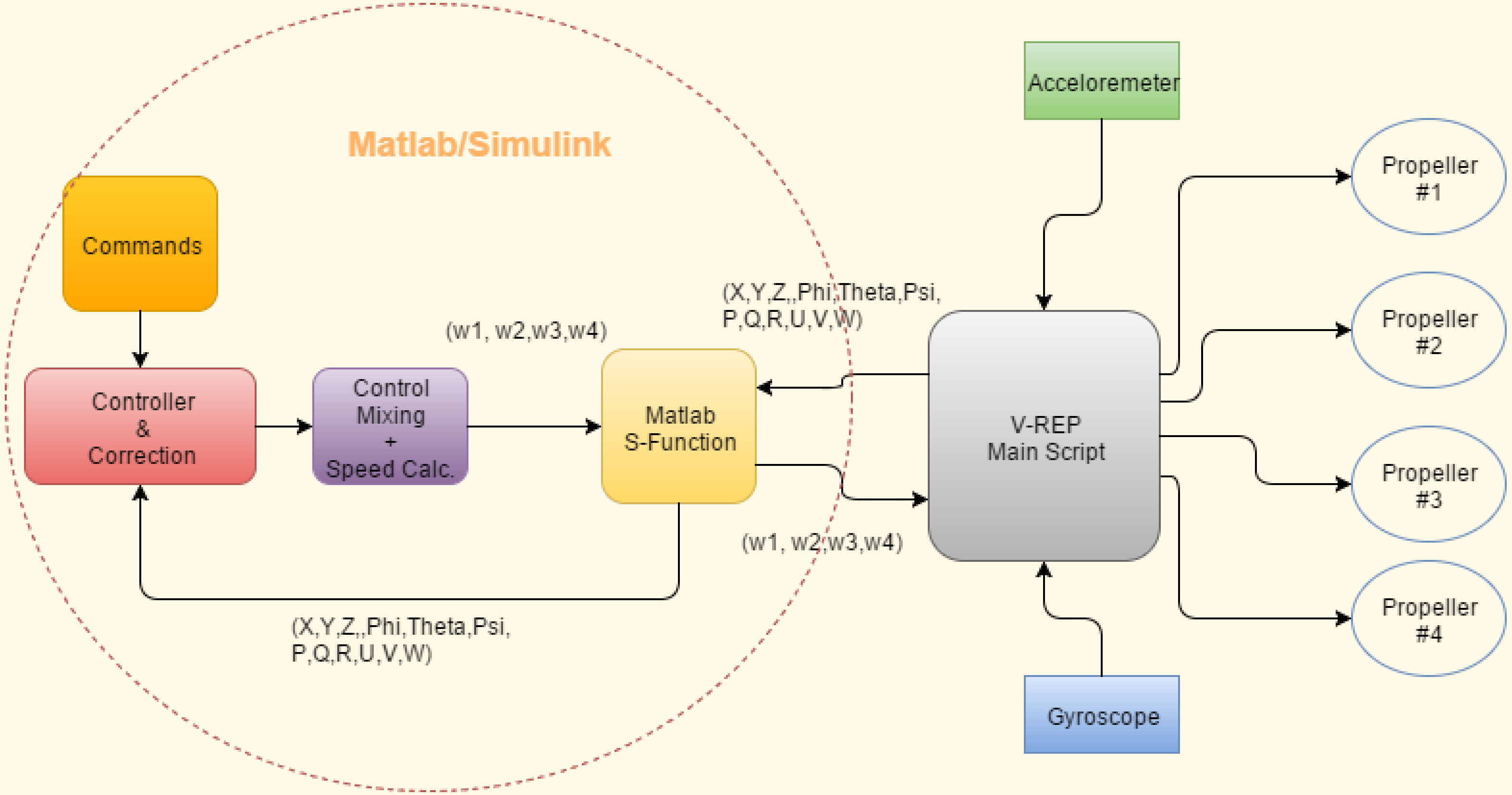


Modeling of Quadrotor in V-REP

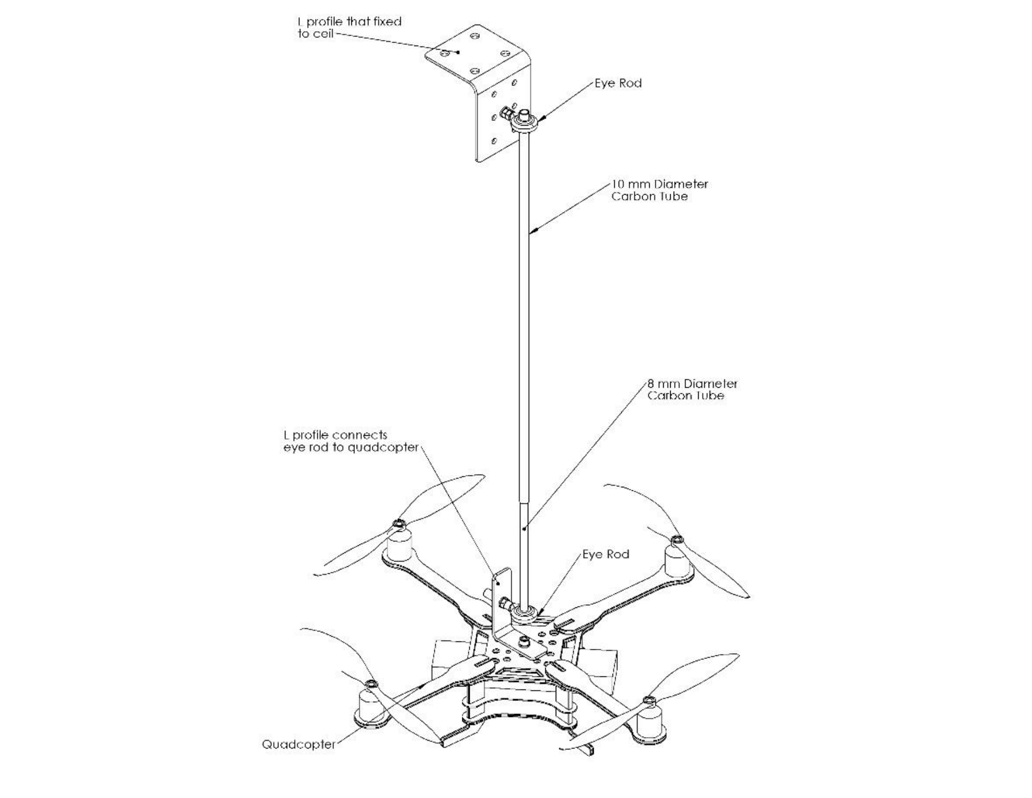
- The propeller of AscTec Hummingbird quadrotor has been modeled in V-REP environment. The experimental data from department thesis have been used in modeling study.
- The quadrotor model file for the Asctec Hummingbird quadrotor is downloaded from the AscTec wiki. The file imported into the V-REP and a simplified dynamic model created for simulation. An appropriate mass and inertia value has been set.
- Developed propeller model has been included to the model.
- Then sensor components like accelerometer, gyroscope and GPS unit has been added to simulation platform.



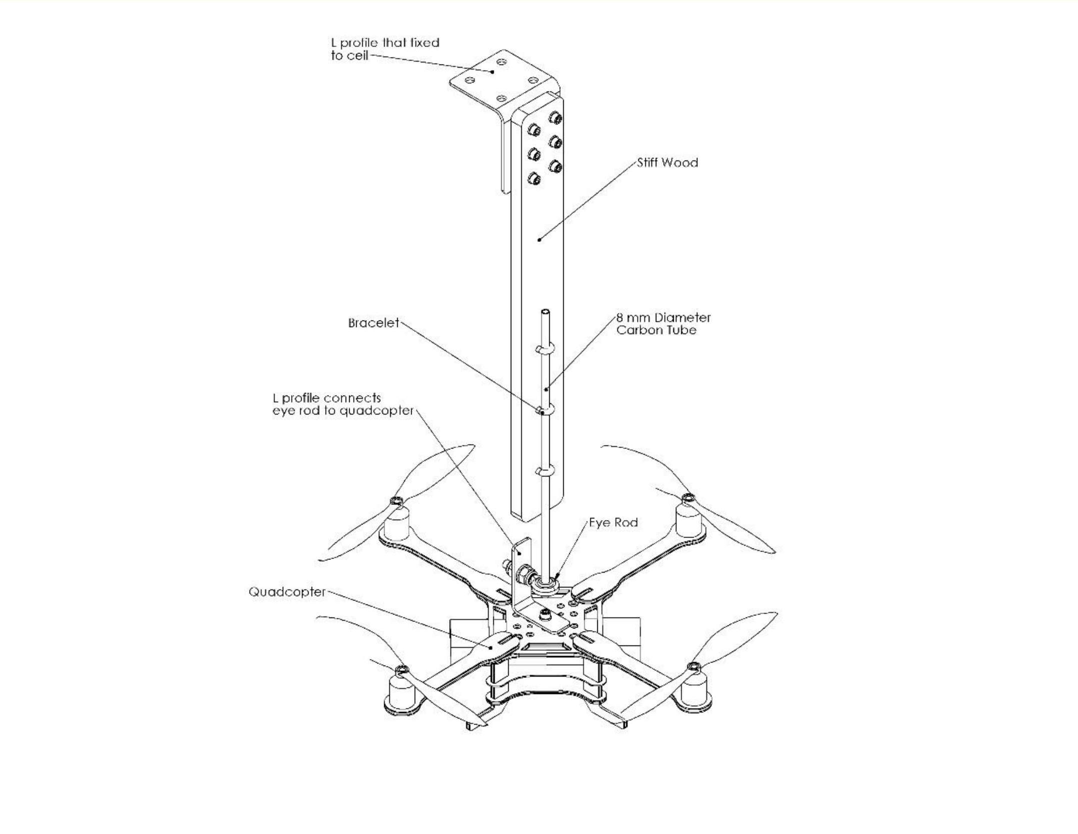
Simulink/Matlab and V-REP Interfacing



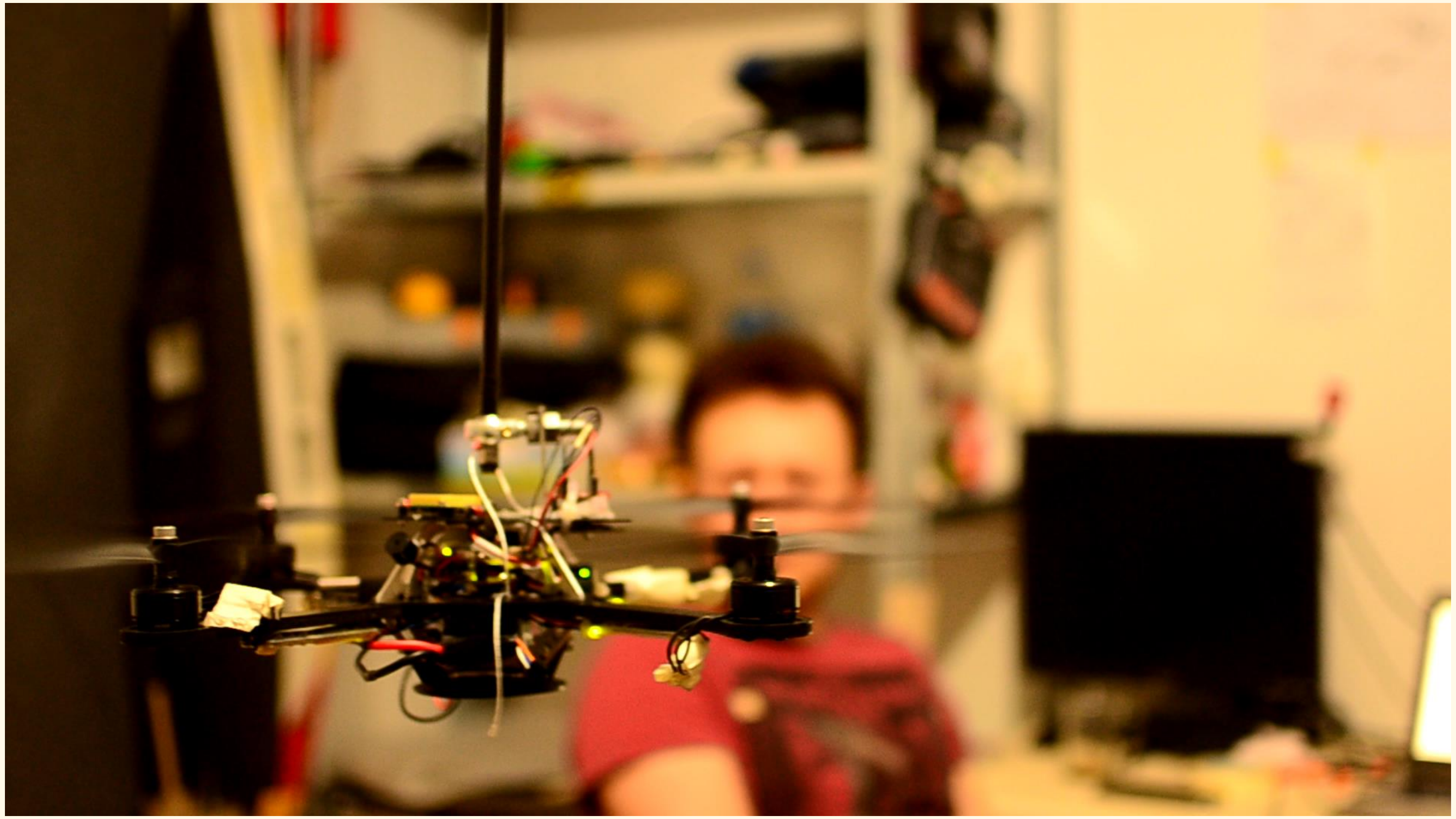
Experimental Setup



Experimental Setup

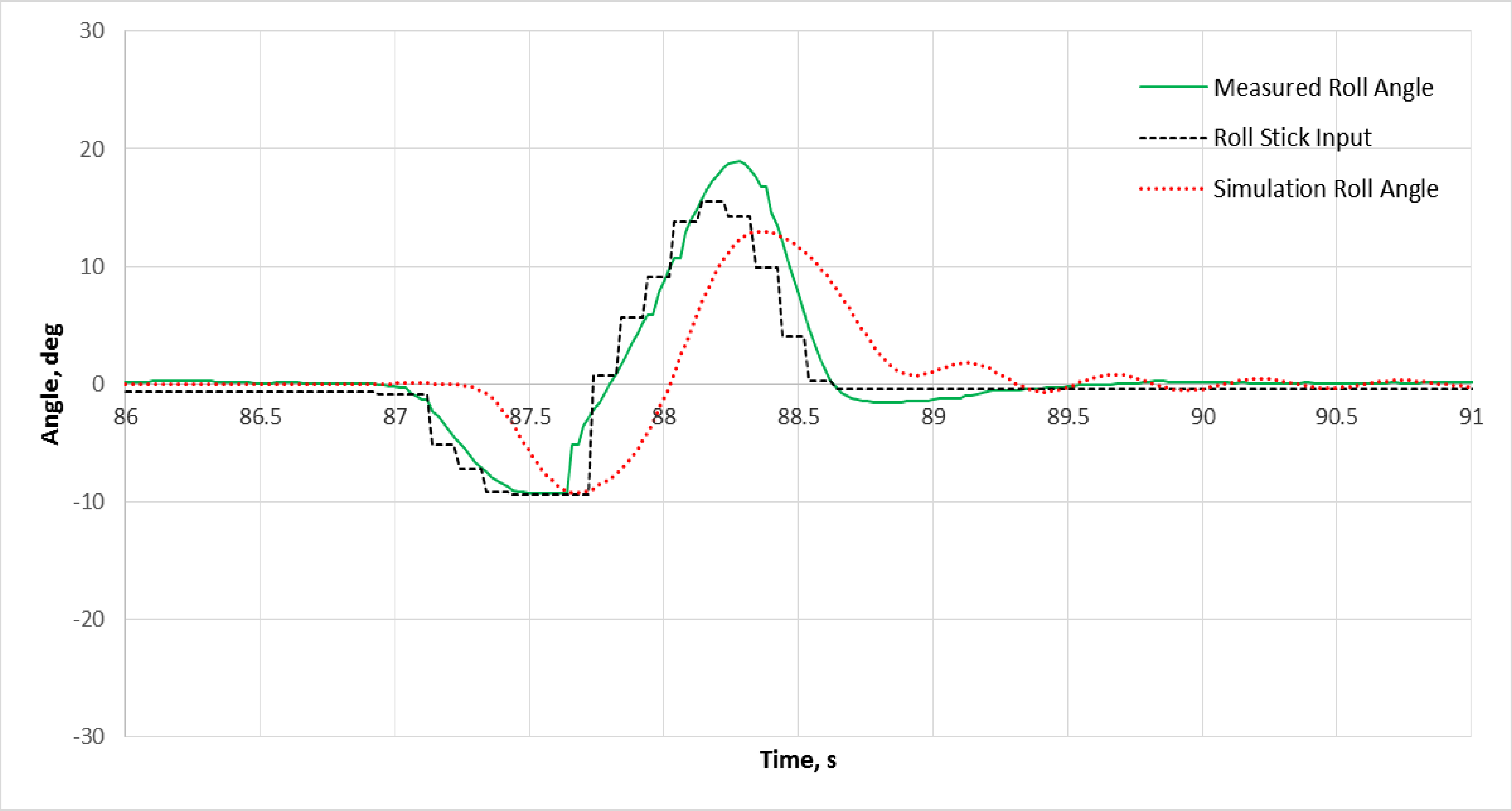


Flight Test



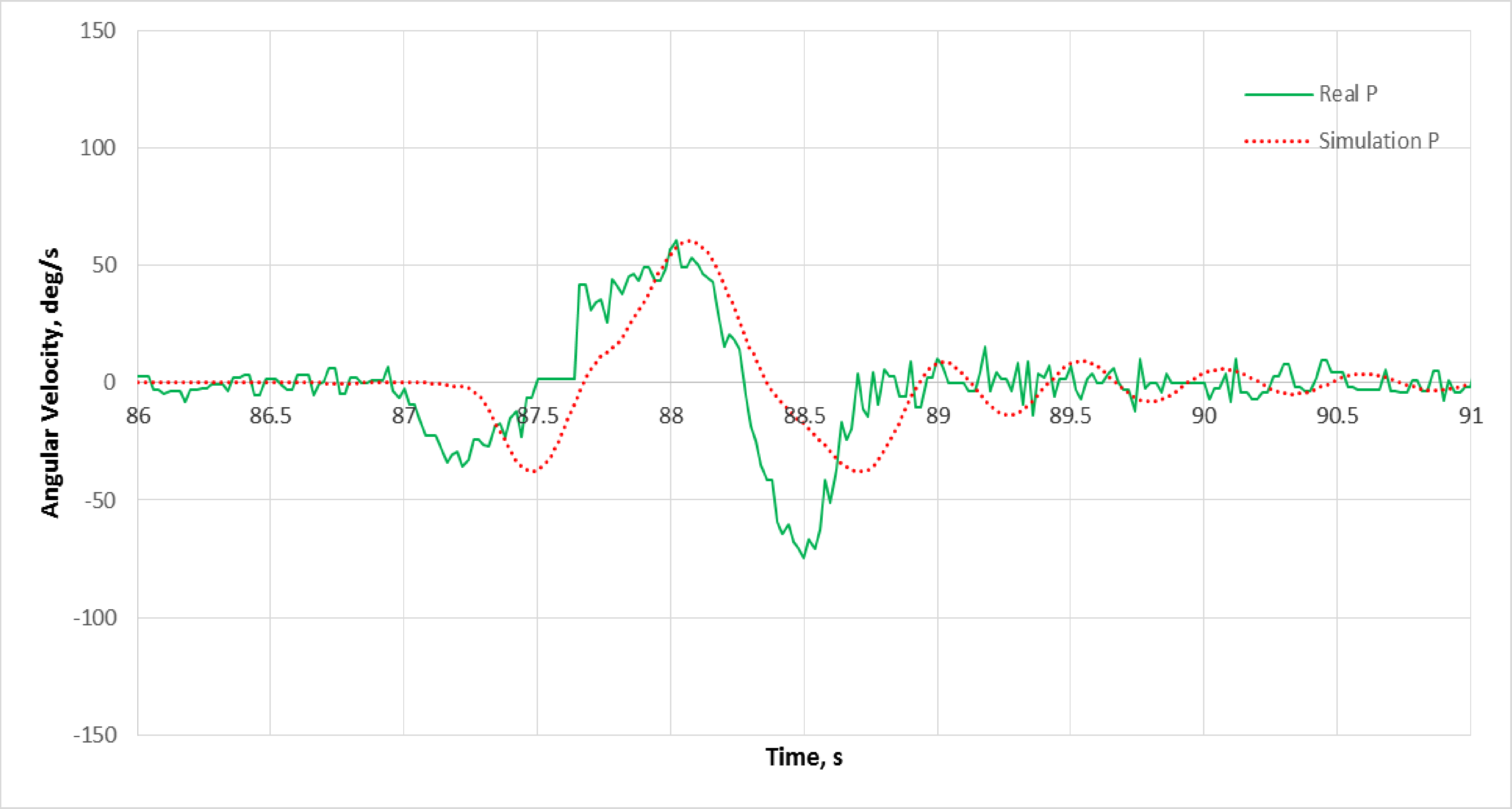
Experimental Results

- Roll angle in directional motion free setup



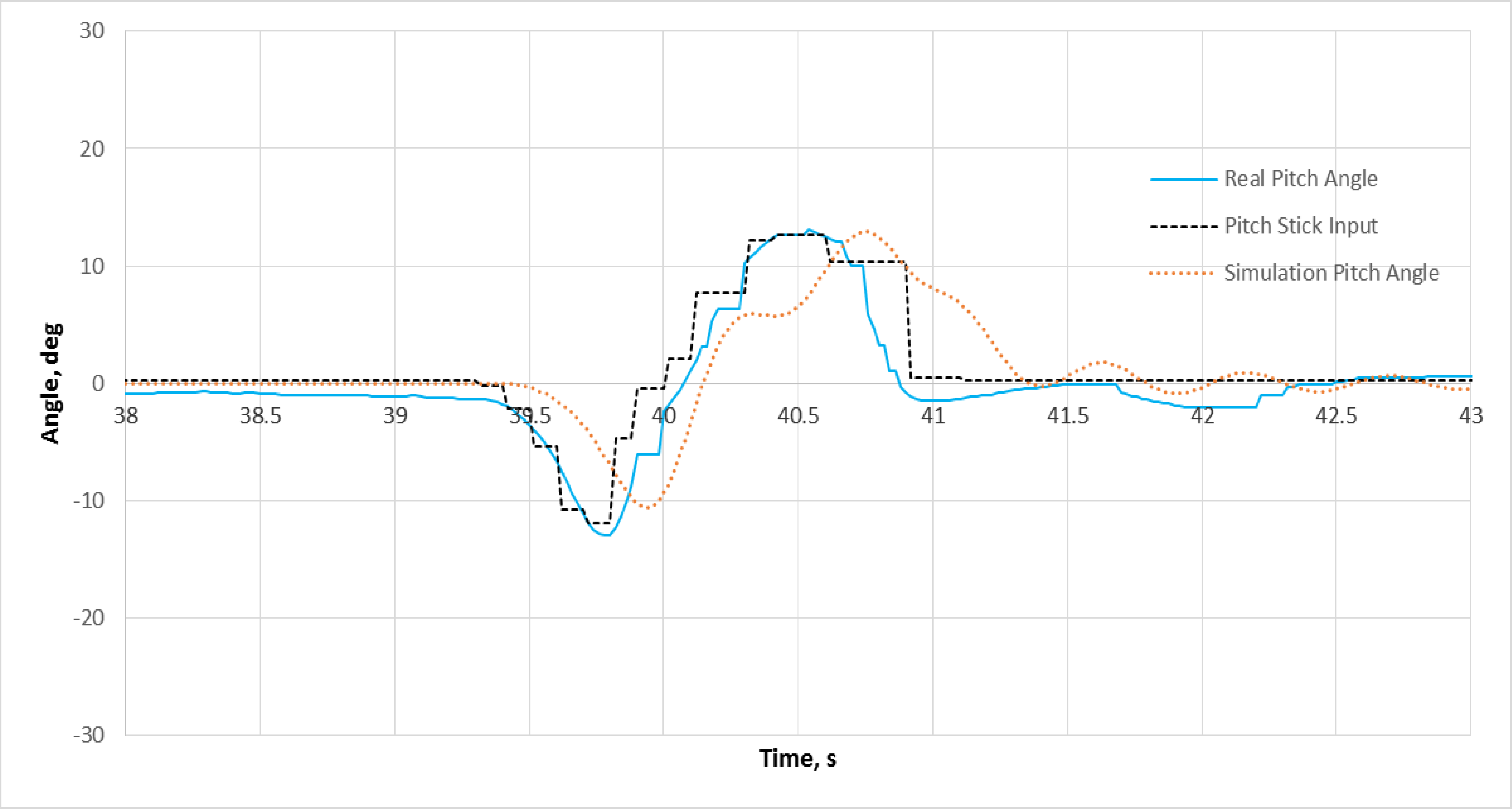
Experimental Results

- Roll angular rate in directional motion free setup



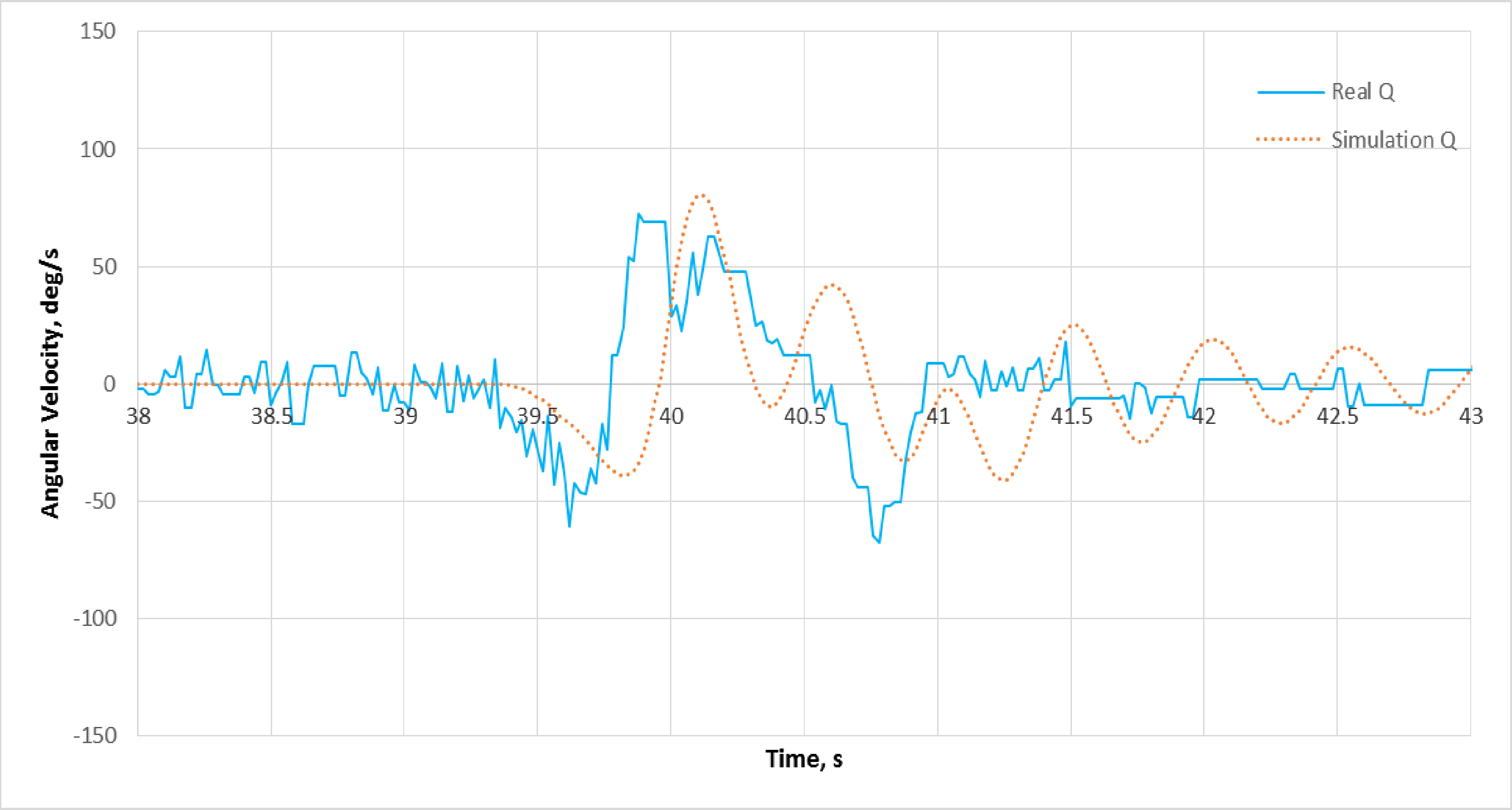
Experimental Results

- Pitch angle in directional motion free setup



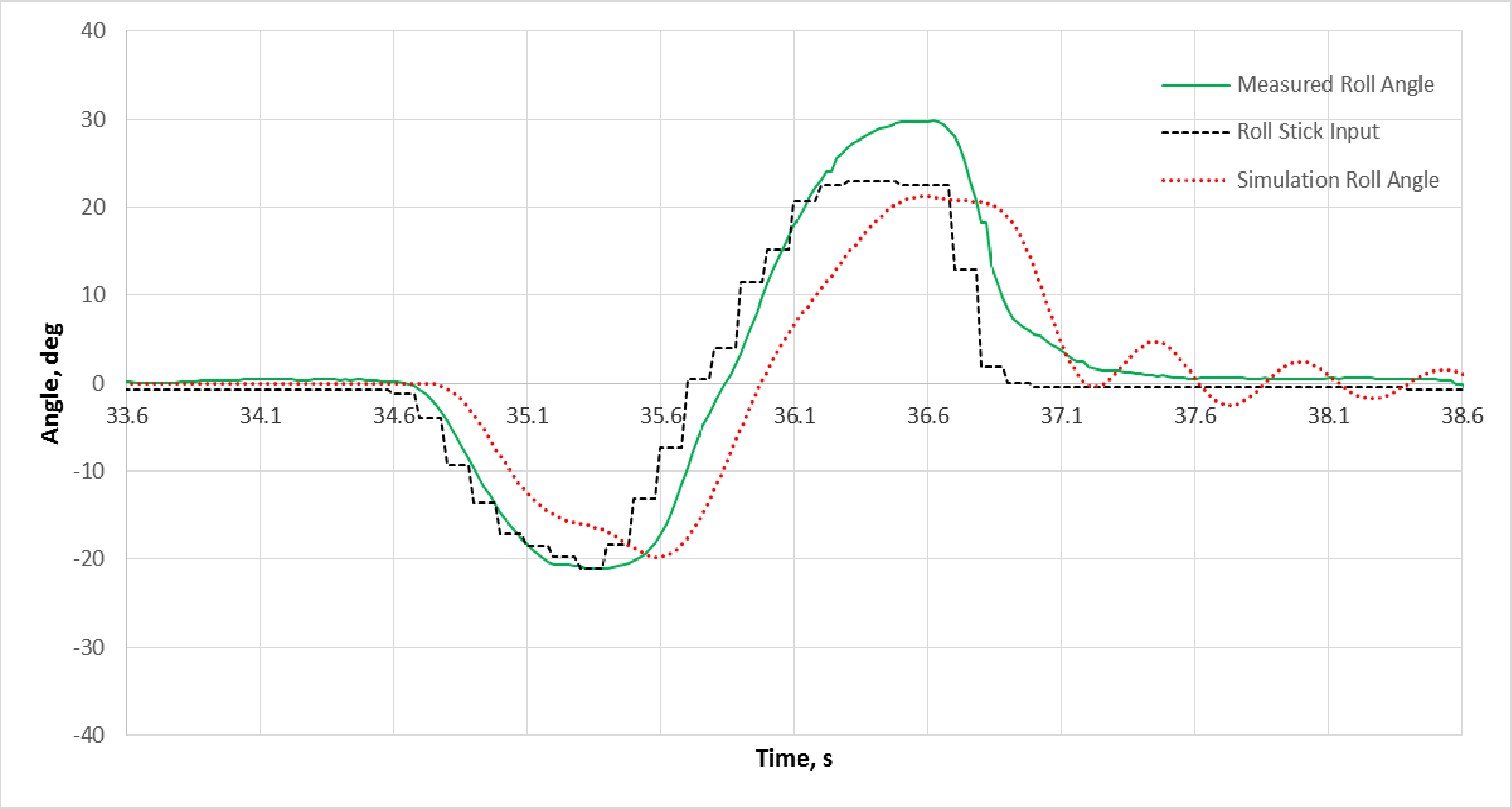
Experimental Results

- Pitch angular rate in directional motion free setup



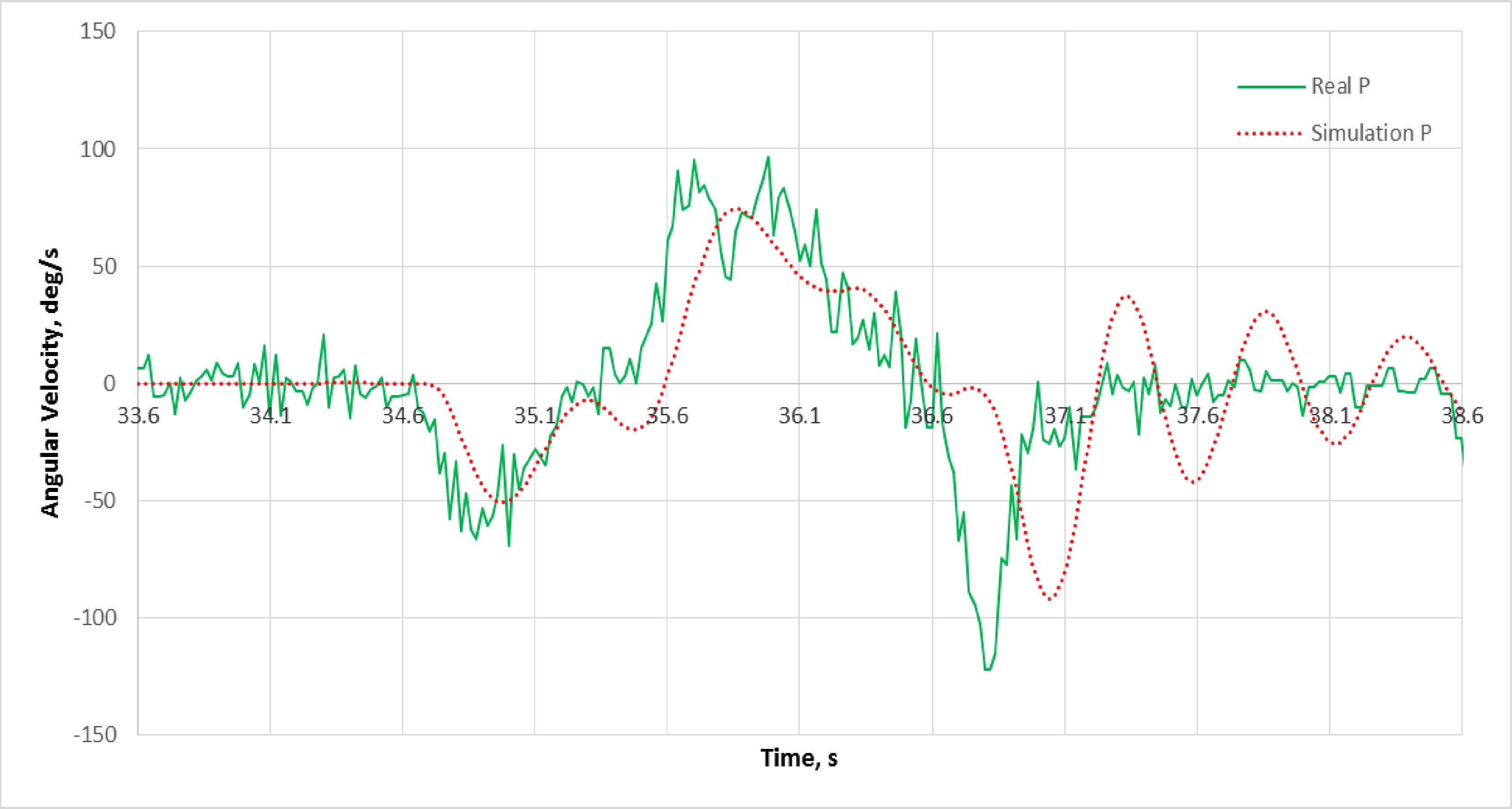
Experimental Results

- Roll angle in directional motion fixed setup



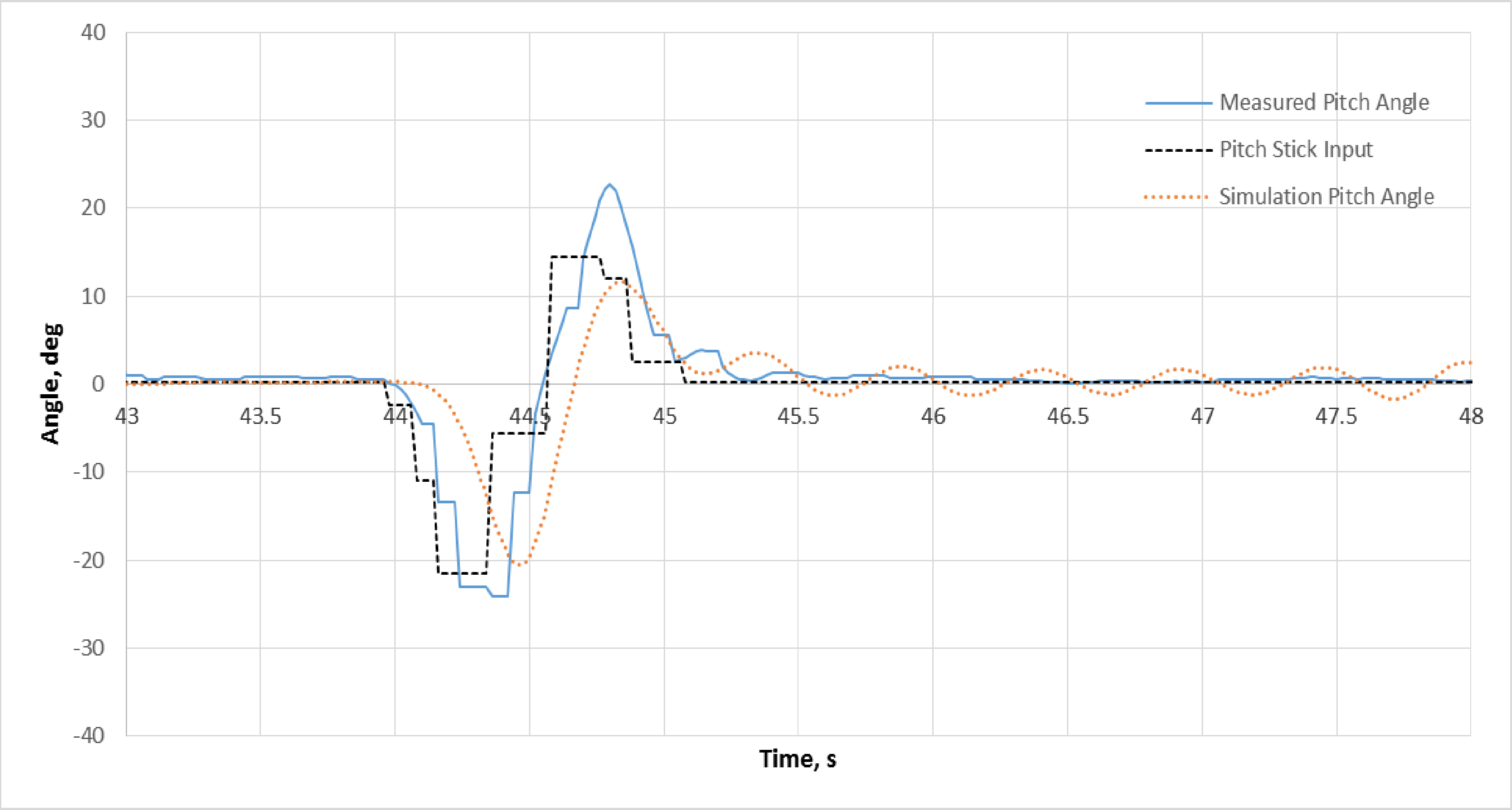
Experimental Results

- Roll angular rate in directional motion fixed setup



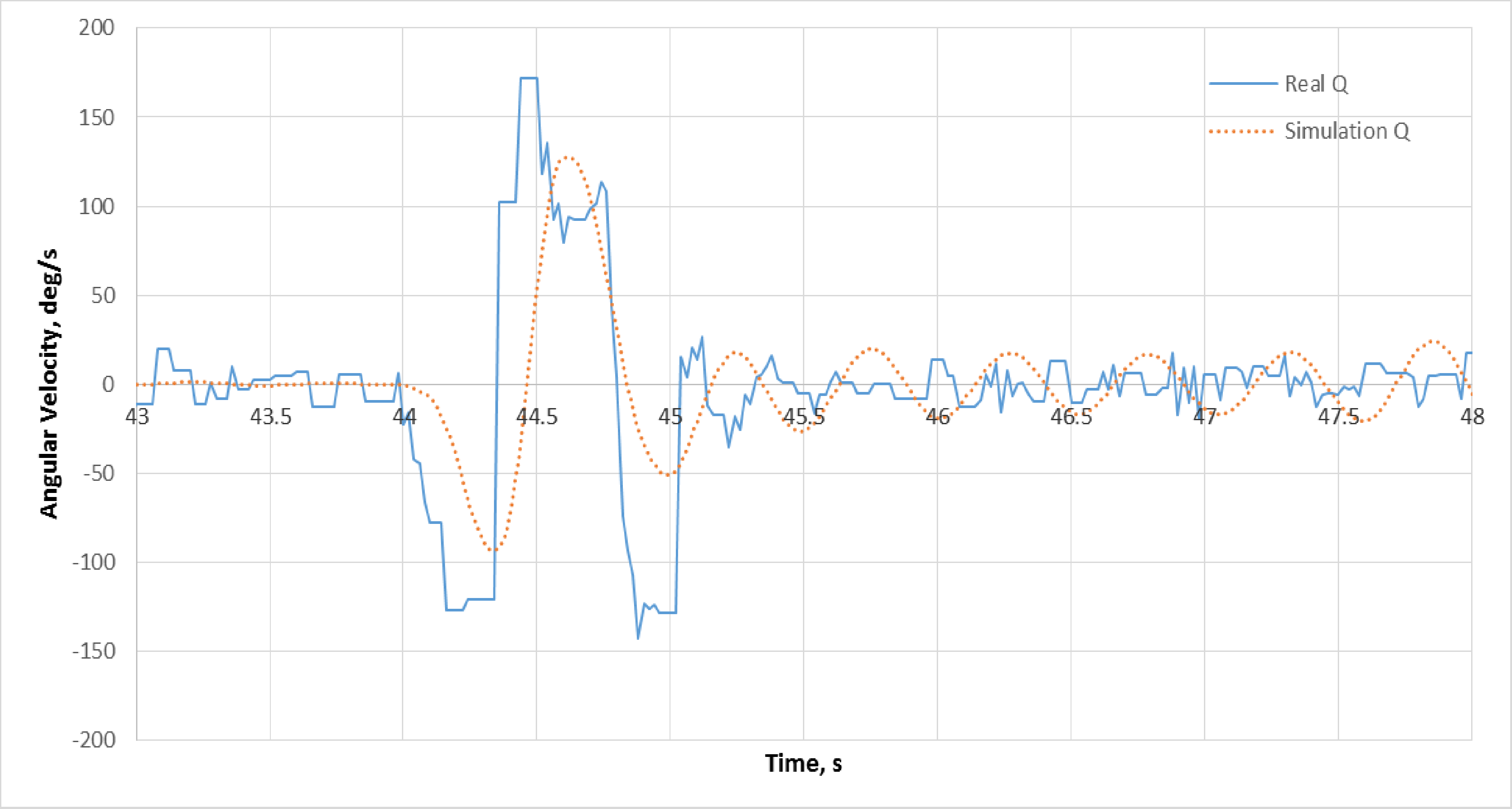
Experimental Results

- Pitch angle in directional motion fixed setup



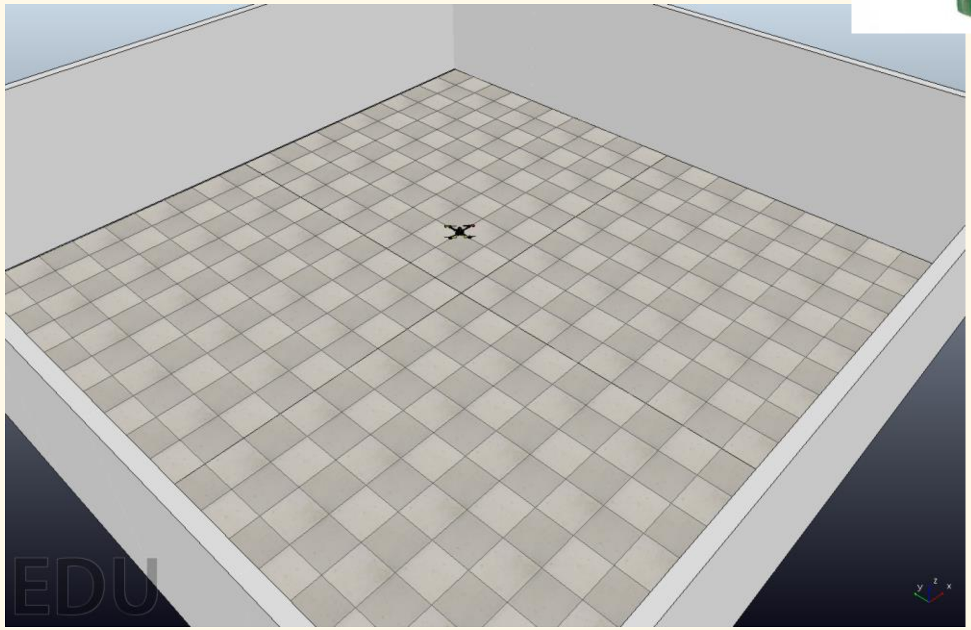
Experimental Results

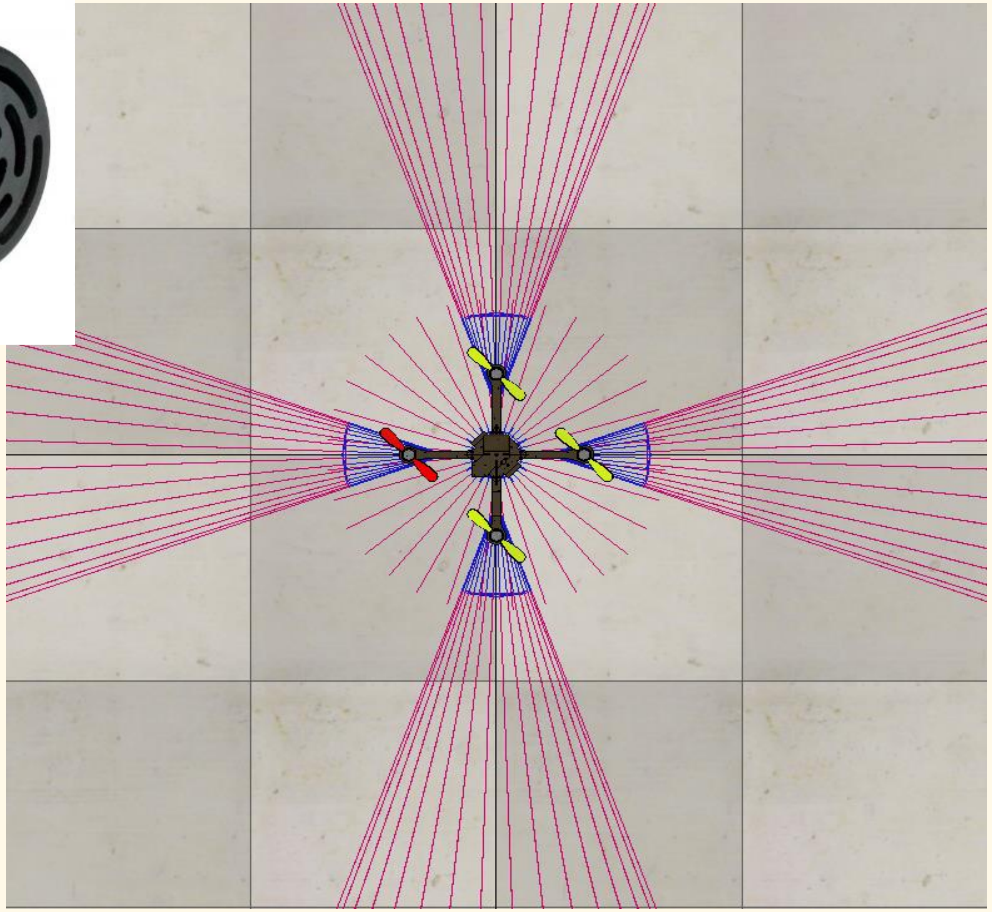
- Pitch angular rate in directional motion fixed setup



Collision Avoidance and Wall Following

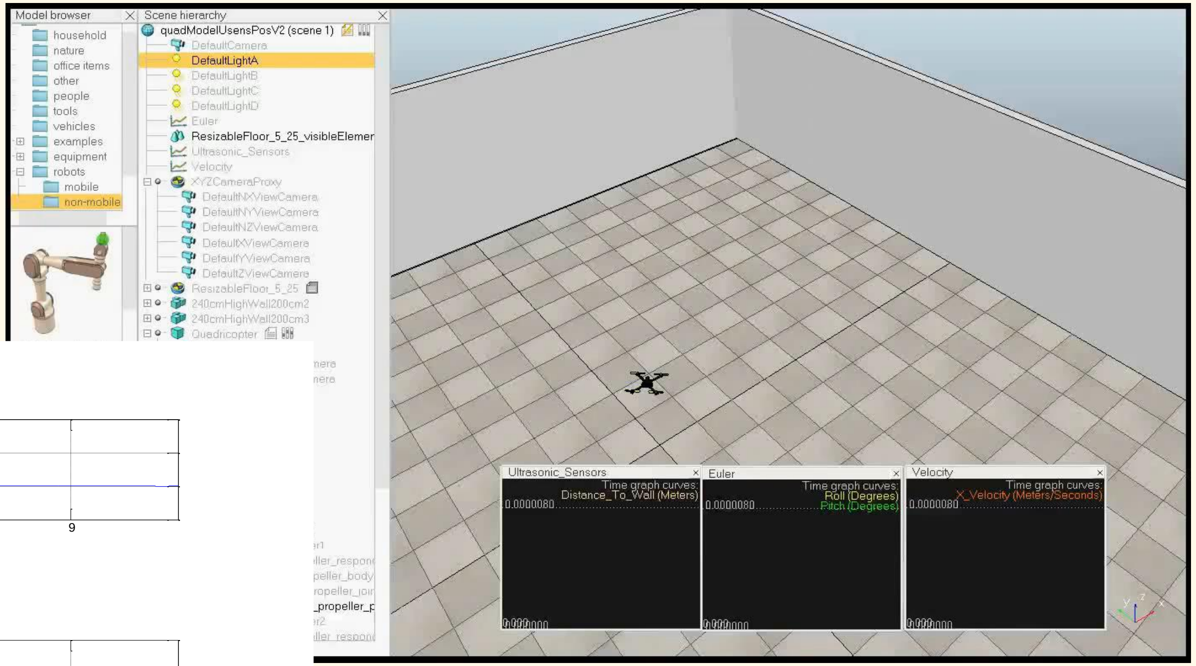
- Ultrasonic sensor Maxbotix XL-MaxSonar-AE0 MB1300
- Four direction and one altitude sensor

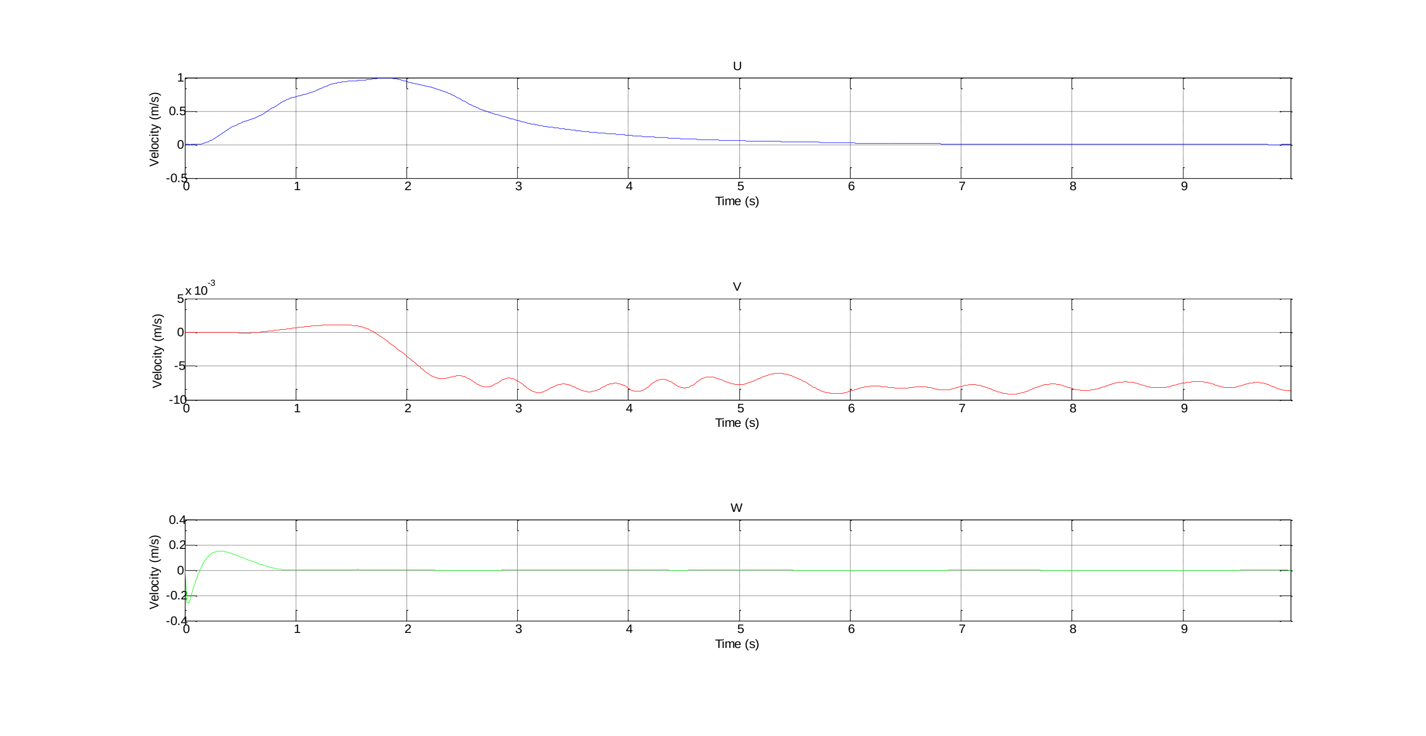




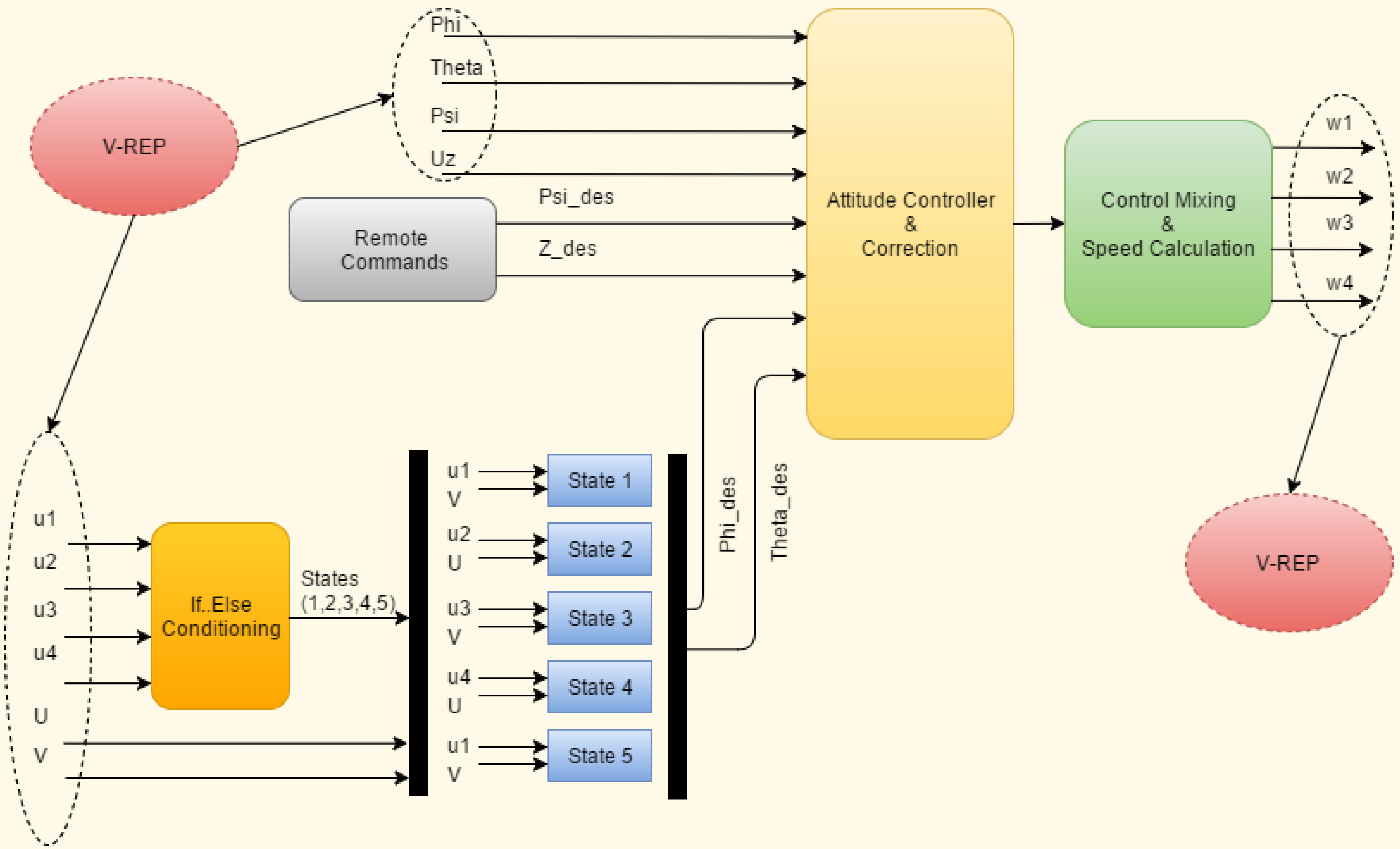
Collision Avoidance and Wall Following

- Stop when wall detected
- PD velocity controller

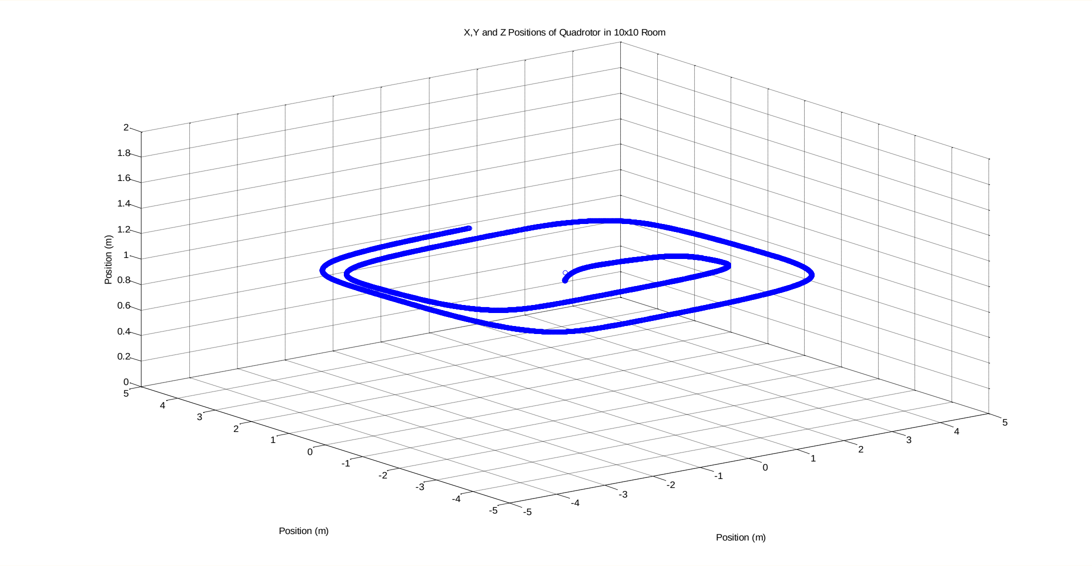


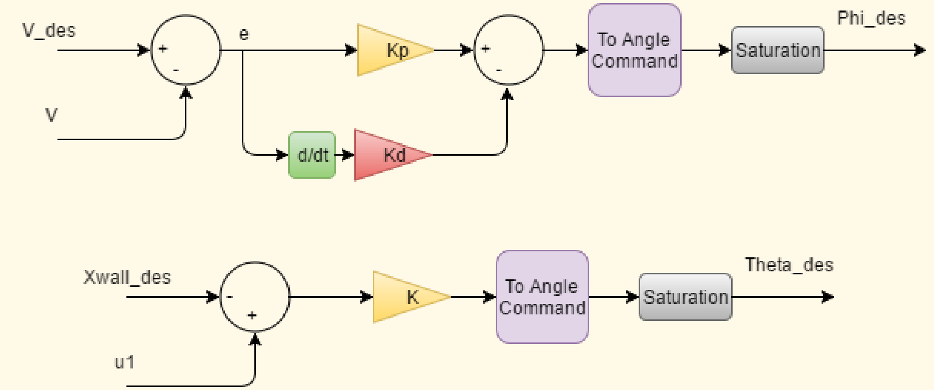


Collision Avoidance and Wall Following

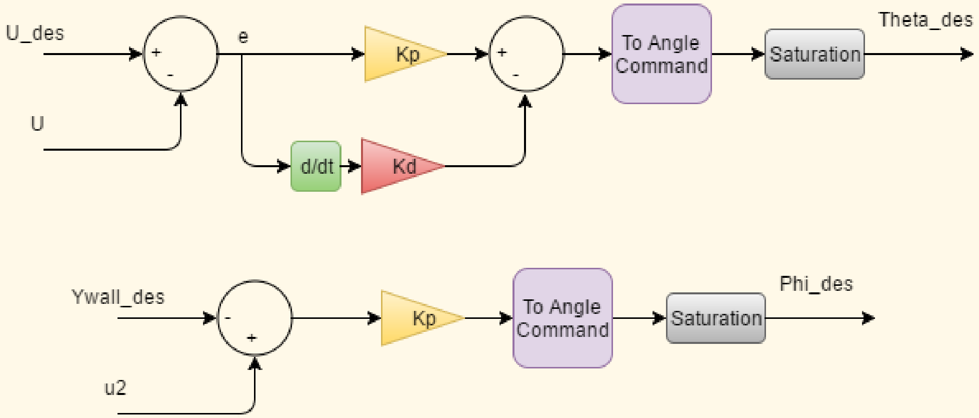


Collision Avoidance and Wall Following



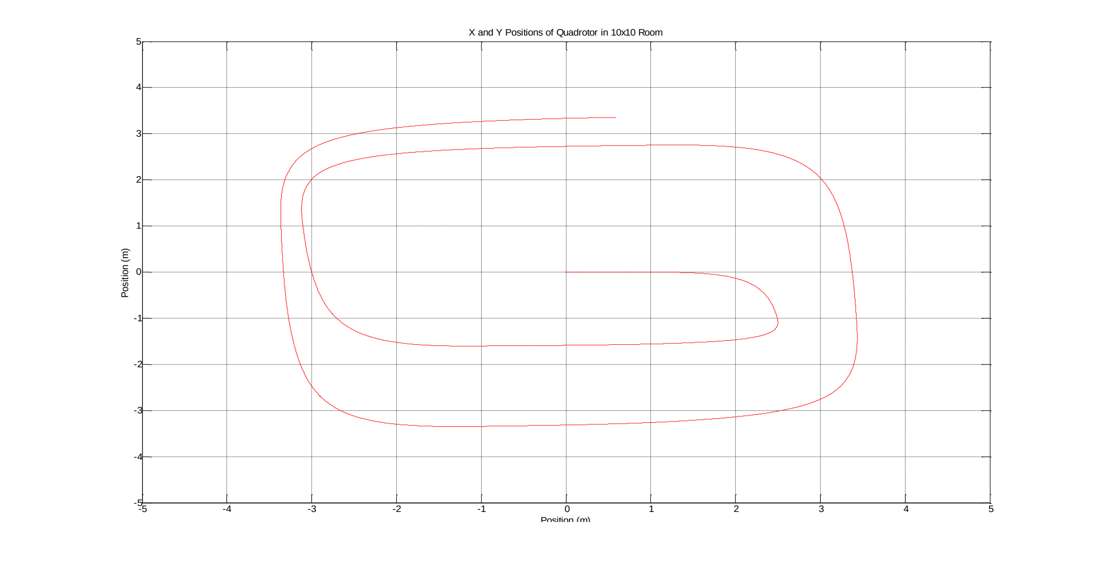


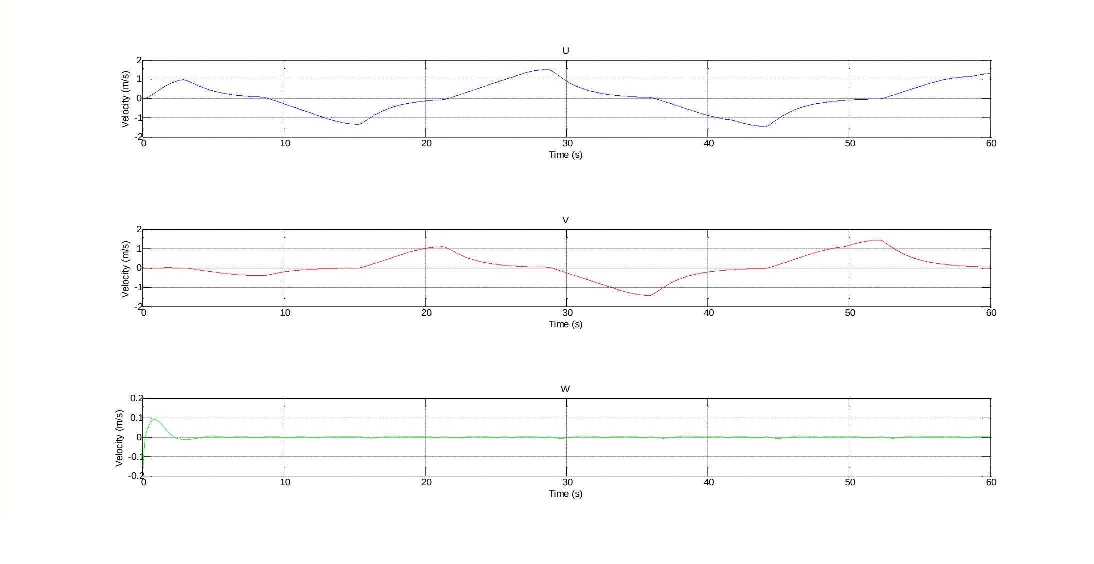
State 1

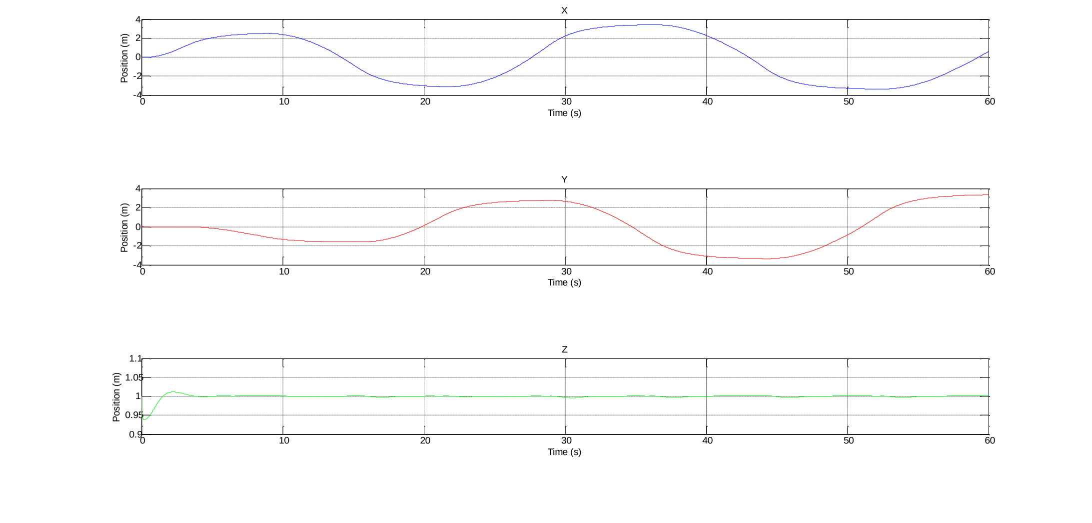


State 2

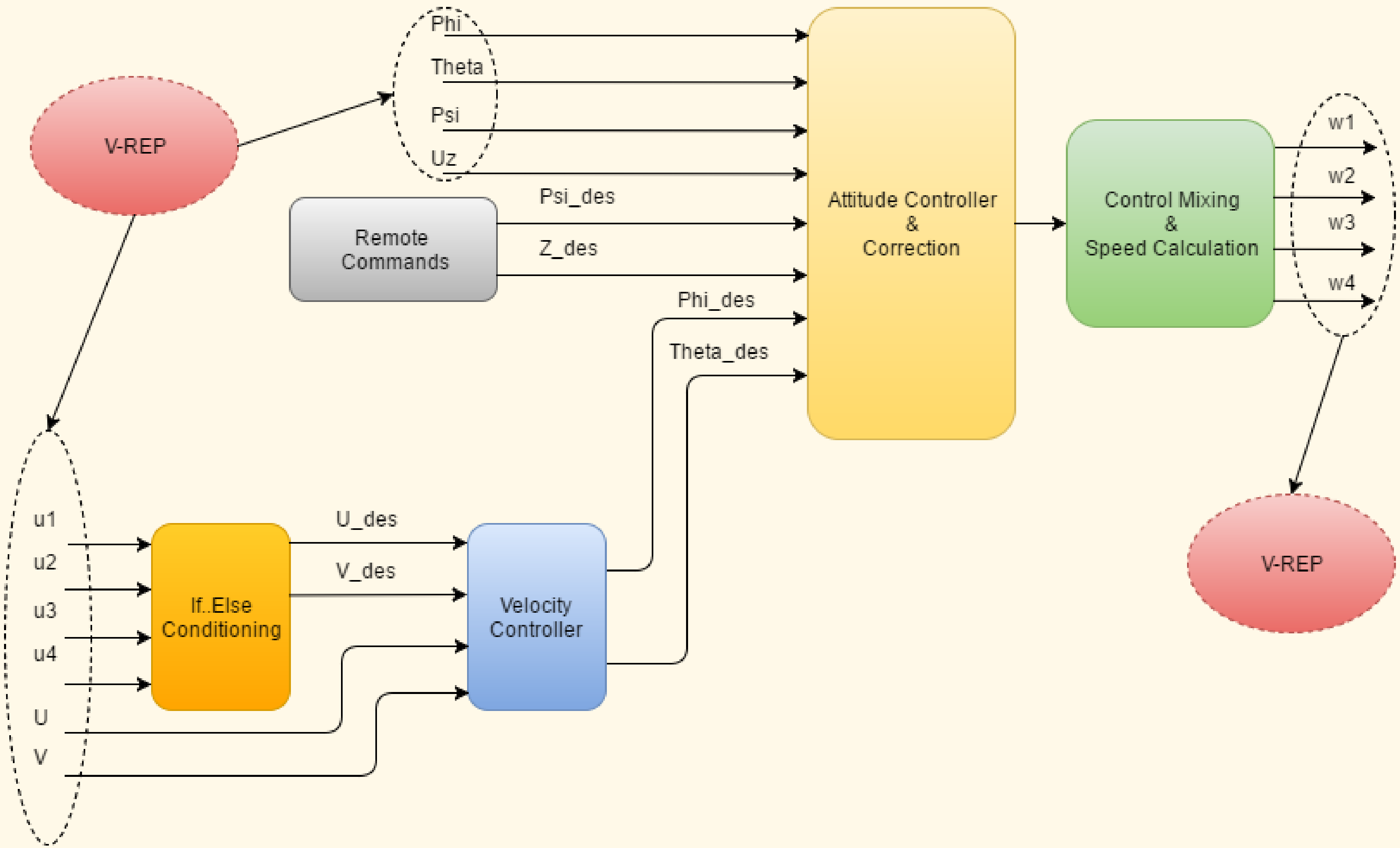
Collision Avoidance and Wall Following



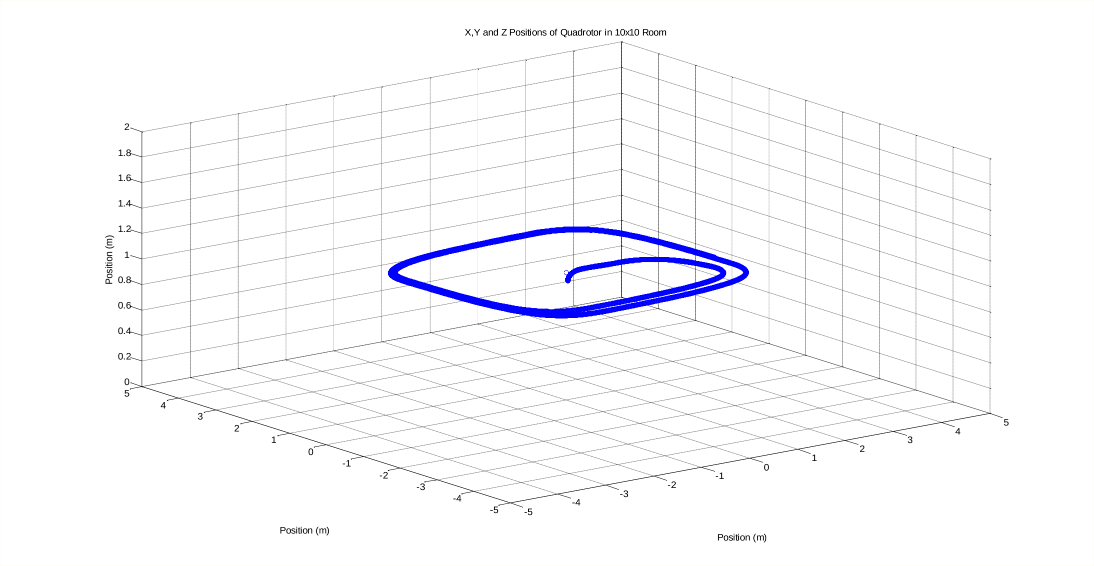


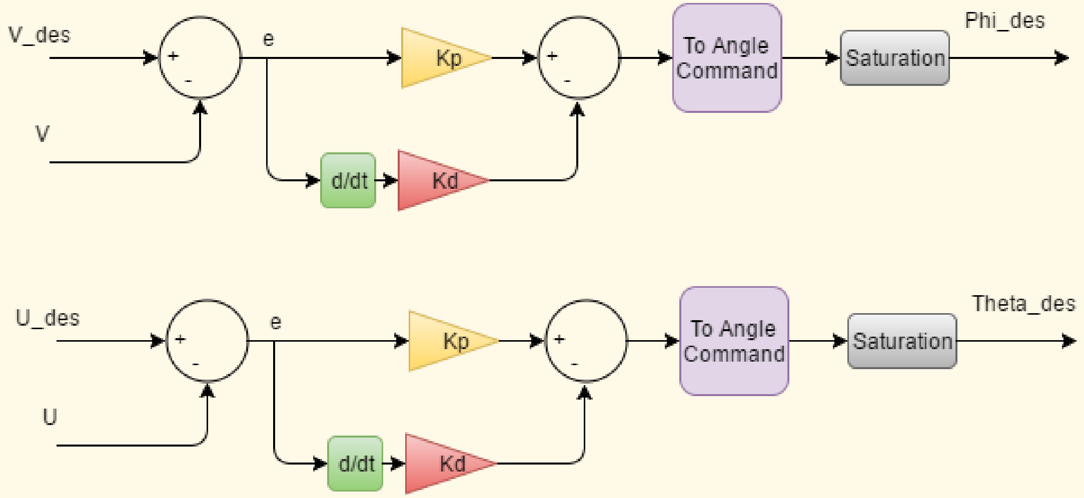


Collision Avoidance and Wall Following



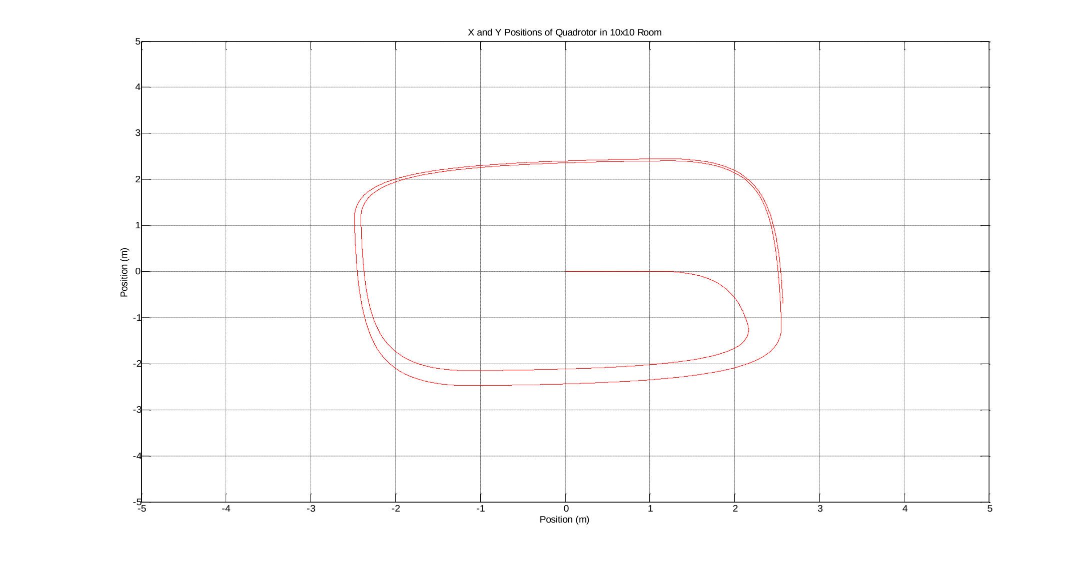
Collision Avoidance and Wall Following

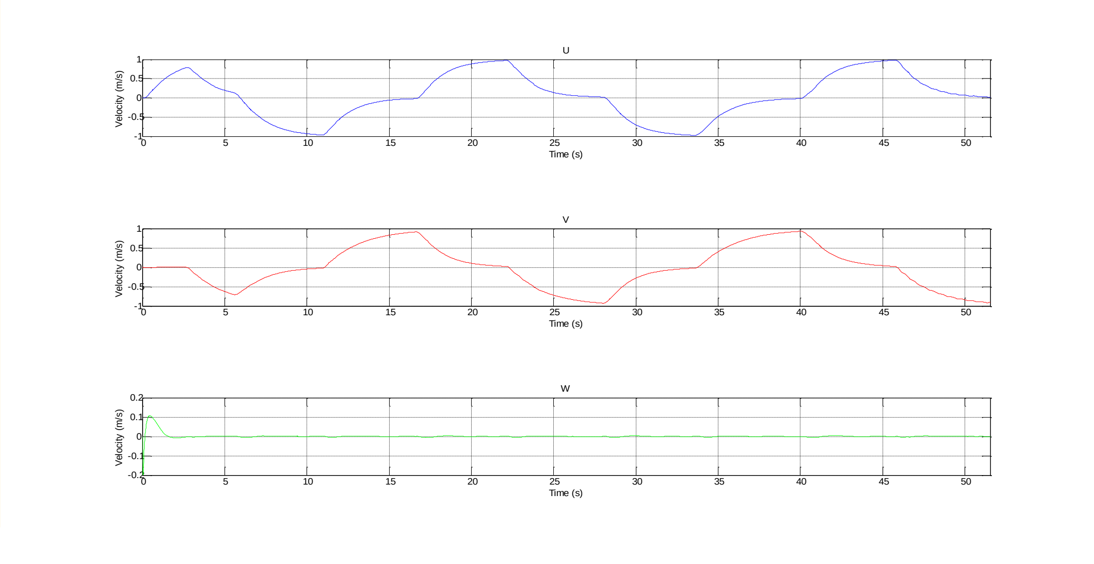


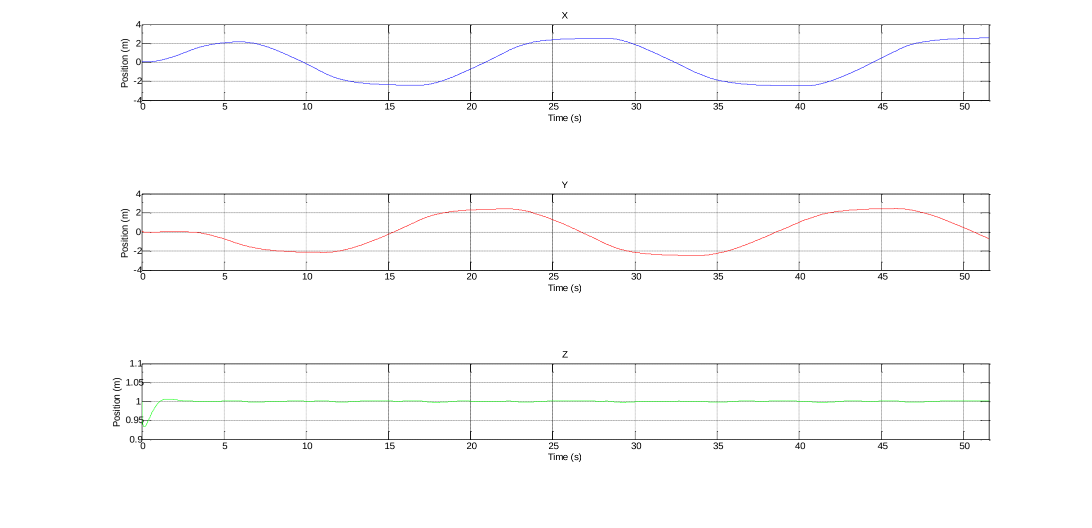


PD Velocity Controller

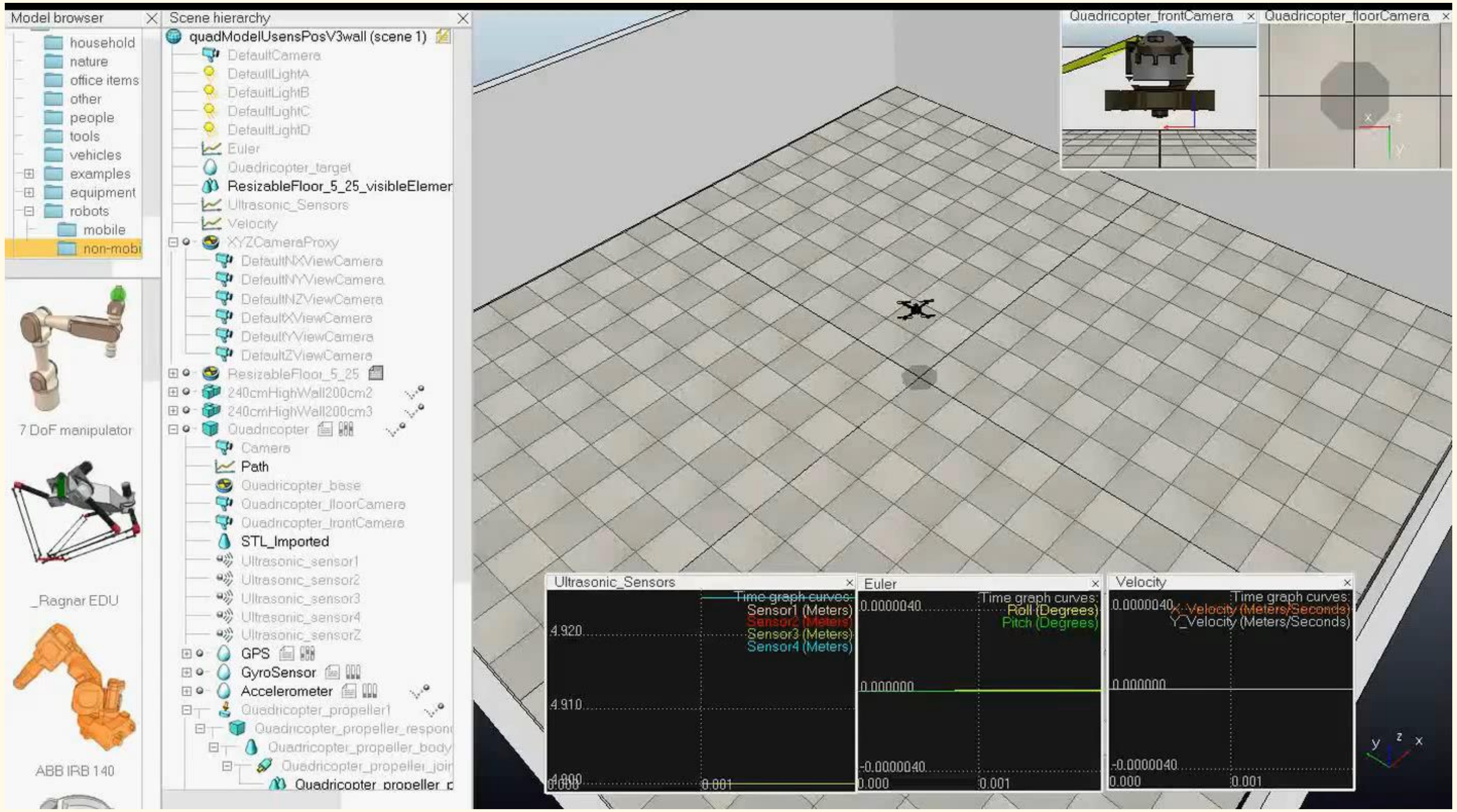
Collision Avoidance and Wall Following







Collision Avoidance and Wall Following

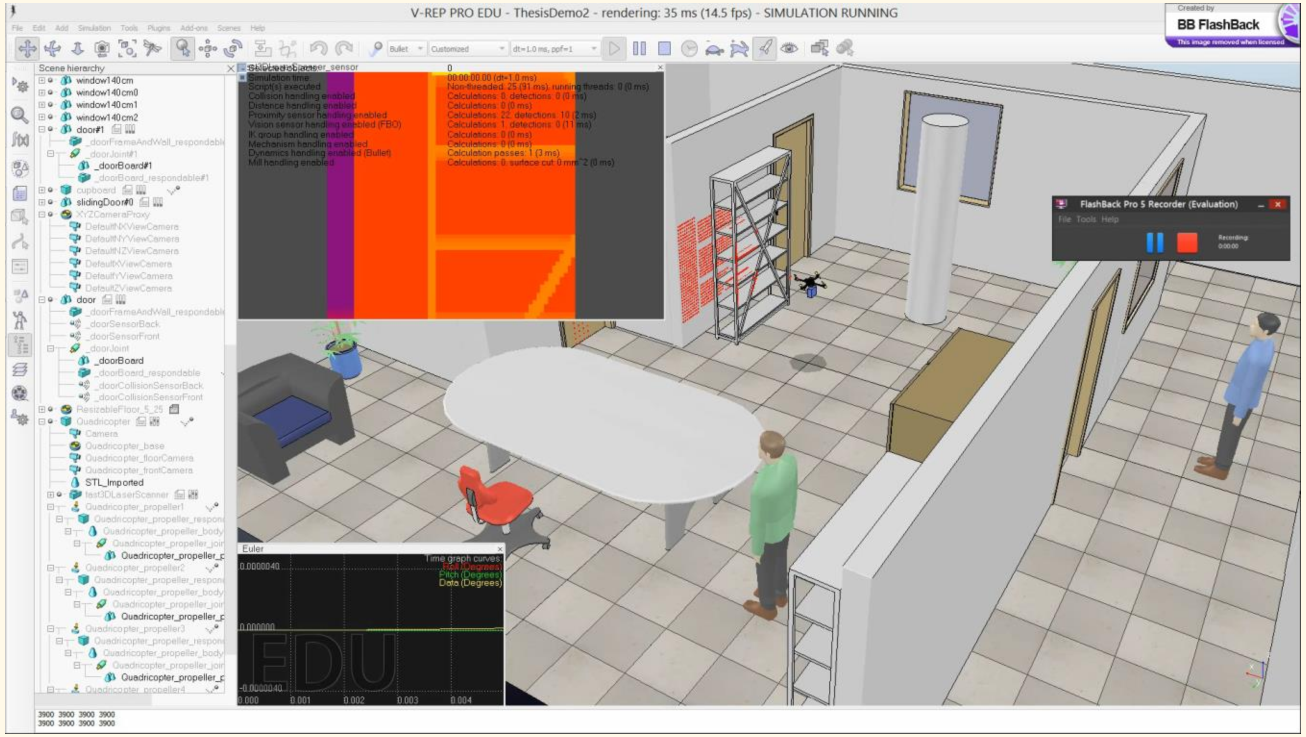


Conclusion

- The dynamic model of the quadrotor is derived and PID controller is designed in Simulink/Matlab platform.
- Full quadrotor model including experimental prop-motor model and sensors is created in V-REP.
- The controller in Simulink/Matlab is interfaced with quadrotor model in V-REP.
- The experimental setup was built and flight test were made.
- The easy use 3-D simulator infrastructure is designed for the test of variety control algorithms in AscTec Hummingbird quadrotor.
- The collision avoidance and wall following algorithms, PD velocity controller have been implemented using ultrasonic sensors according to the implementation of study.

Conclusion

- The quadrotor flight in office environment equipped with 3D Laser Scanner



Future Work

- Addition of more detailed IMU model
- Other classical and nonlinear control algorithms
- Adding 2-D, 3-D vision sensor for localization and mapping algorithm tests
- Collision avoidance algorithms
- The costly sensors can be achieved and simulator based developed algorithms can be implemented on real quadrotor.

References

- [1] https://www.youtube.com/watch?v=_sUeGC-8dyk
- [2] http://www.bbc.com/news/business-33849026
- [3] S. L. and G. M. Hoffmann, "Multi-Agent Quadrotor Testbed Control Design:Integral Sliding Mode vs. Reinforcement Learning," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2005.
- [4] K. Karwoski, "Quadrocopter Control Design and Flight Operation," NASA USRP – Internship Final Report.

Thank you for your kind attention

Any questions ???