Integral LQR-Based 6DoFs Autonomous Quadrocopter Balancing System Control

Faculty of Electrical & Electronic Engineering | Dept. of Mechatronics Engineering

A. Joukhadar, BSc, MPhil, PhD
joukhadar2703@yahoo.co.uk

Ammar Alsabbagh, BSc
ammar-alsabbagh-eng@hotmail.com

Ibrahim Hasan, BSc
ibrahim_hasan_eng@hotmail.com

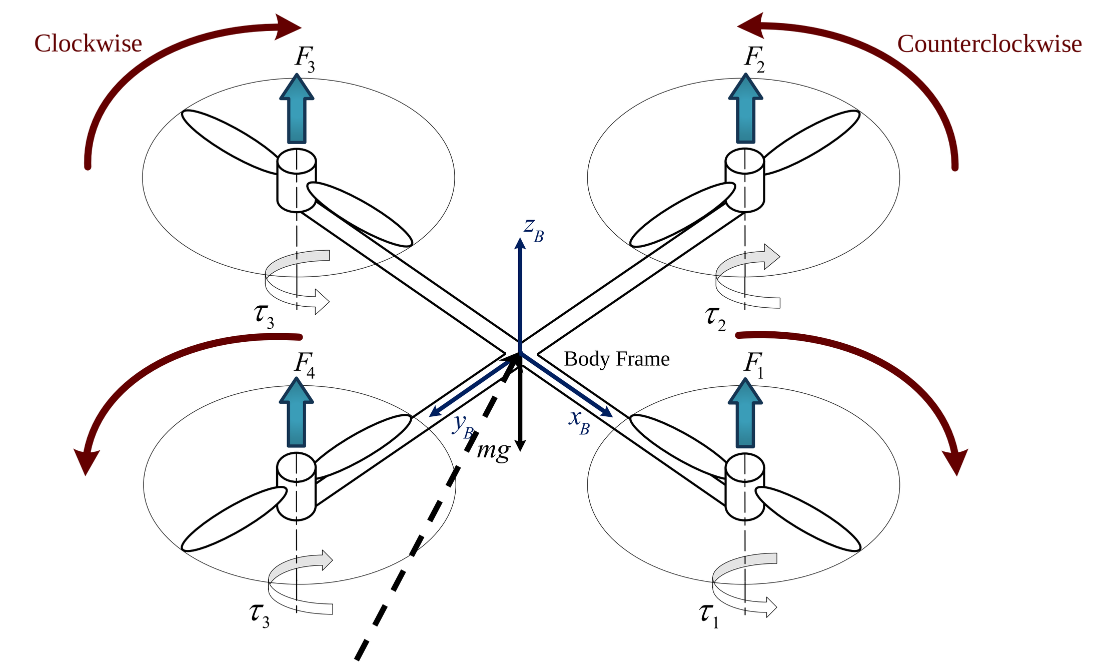
Mouaz Alkouzbary, BSc
mouaz.k@live.com

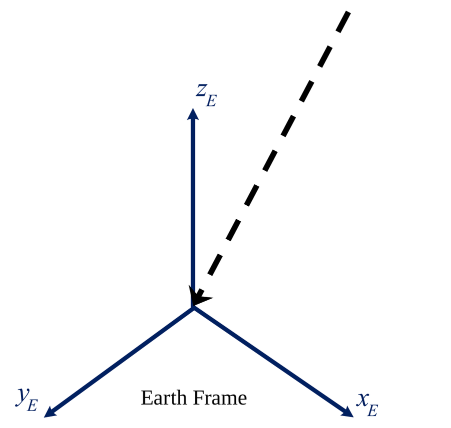
Abstract

This poster presents an LQR-based 6DoFs control of unmanned aerial vehicles (UAVs), namely a small-scale quadrocopter. Due to its high nonlinearity and high degree of coupling system, the control of a UAV is very challenging. Quadrocopter trajectory tracking in a 3D space is greatly affected by the quadrocopter balancing around its roll-pitch-yaw frame. Lack of precise tracking control about the body frame may result in inaccurate localization with respect to a fixed frame. An integral-LQR-based controller is proposed to enhance the dynamic system response balancing on roll, pitch and yaw. The control on the hovering angles consists of two-cascaded loops: an inner loop for the angular speed control of each angular motion around the body frame axes, and an outer loop for the desired position control. In general, the proposed balancing control system on roll, pitch and yaw has six control loops. Practical results obtained from the developed control algorithm implemented utilizing ATMega 2560 coincides with the simulation results conducted from the developed nonlinear dynamic model of the UAV built-in C language. The proposed control approach exhibits fast control response and high disturbance rejection.

Introduction

With the development of micro-electronic technologies, the UAV draw a lot of attention in recent years due to its advantages of compact size, agility and autonomous flight. The UAVs are expected to become much more common soon because of their potential in preventing pilot exposure to danger. The main goal of the research is to develop an integral LQR controller to enhance the dynamic control response of the quadrocopter with respect to the quadrocopter body frame. The body-frame control was accomplished practically, whilst the fixed-frame control was only achieved in the simulation field.





The movement of the vehicle's body frame with respect to the inertial earth frame is controlled by adjusting the angular speed of the propellers properly. Control laws will lead the vehicle to act in a particular manner as desired.

Dynamic Model of a Quadrocopter

$$
\left.\begin{aligned}
\ddot{x} &= (C_\phi S_\theta C_\psi + S_\phi S_\psi)\frac{1}{m}U_1\\
\ddot{y} &= (C_\phi S_\theta S_\psi - S_\phi C_\psi)\frac{1}{m}U_1\\
\ddot{z} &= -g + (C_\phi C_\theta)\frac{1}{m}U_1\\
\ddot{\phi} &= \dot{\theta}\dot{\psi}\left[\frac{I_{yy}-I_{zz}}{I_{xx}}\right] + \frac{J_r}{I_{xx}}\dot{\theta}\Omega_d + \frac{l}{I_{xx}}U_2\\
\ddot{\theta} &= \dot{\phi}\dot{\psi}\left[\frac{I_{zz}-I_{xx}}{I_{yy}}\right] - \frac{J_r}{I_{yy}}\dot{\phi}\Omega_d + \frac{l}{I_{yy}}U_3\\
\ddot{\psi} &= \dot{\theta}\dot{\phi}\left[\frac{I_{xx}-I_{yy}}{I_{zz}}\right] + \frac{1}{I_{zz}}U_4
\end{aligned}\right\} \quad (1)
$$

Equations (1) present the complete mathematical equations for the unmanned vehicle, quadrocopter.

To achieve optimal control algorithm, Linear Quadratic Regular (LQR), the dynamic model, described in (1), must be linearized around a trim condition, which is chosen to be hover condition.

Dynamic Model of a Quadrocopter

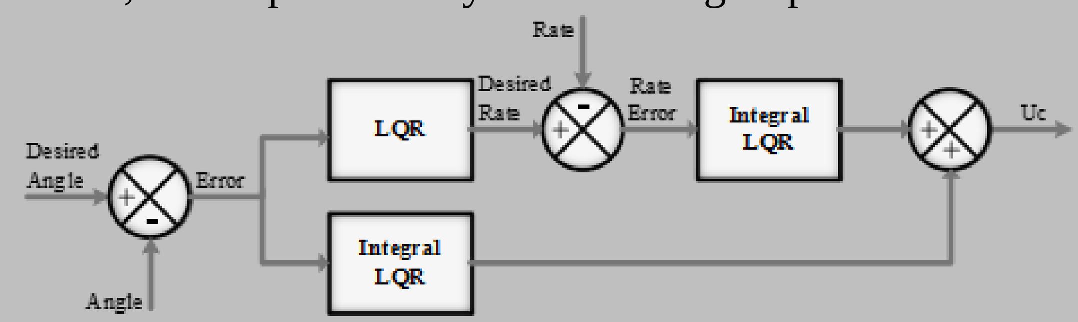
The linearized system structure can be divided into subsystems written in the system state space as shown in (2).

$$
\left.\begin{aligned}
\begin{bmatrix}\dot{x}_{\phi,1}\\ \dot{x}_{\phi,2}\end{bmatrix} &= \begin{bmatrix}0&1\\0&0\end{bmatrix}\begin{bmatrix}x_{\phi,1}\\ x_{\phi,2}\end{bmatrix} + \begin{bmatrix}0\\ c_1\end{bmatrix}U_2\\
\begin{bmatrix}\dot{x}_{\theta,3}\\ \dot{x}_{\theta,4}\end{bmatrix} &= \begin{bmatrix}0&1\\0&0\end{bmatrix}\begin{bmatrix}x_{\theta,3}\\ x_{\theta,4}\end{bmatrix} + \begin{bmatrix}0\\ c_2\end{bmatrix}U_3\\
\begin{bmatrix}\dot{x}_{\psi,5}\\ \dot{x}_{\psi,6}\end{bmatrix} &= \begin{bmatrix}0&1\\0&0\end{bmatrix}\begin{bmatrix}x_{\psi,5}\\ x_{\psi,6}\end{bmatrix} + \begin{bmatrix}0\\ c_3\end{bmatrix}U_4
\end{aligned}\right\} \quad (2)
$$

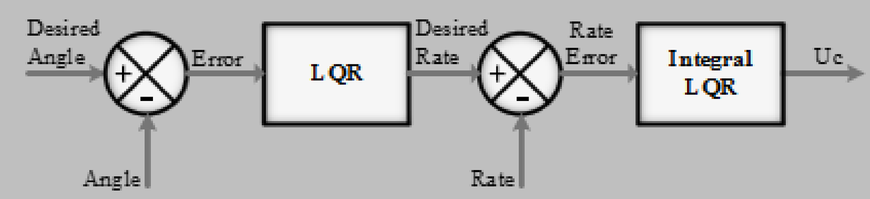
Whereas,

$$c_1 = l/I_{xx},\ c_2 = l/I_{yy},\ c_3 = l/I_{zz}$$

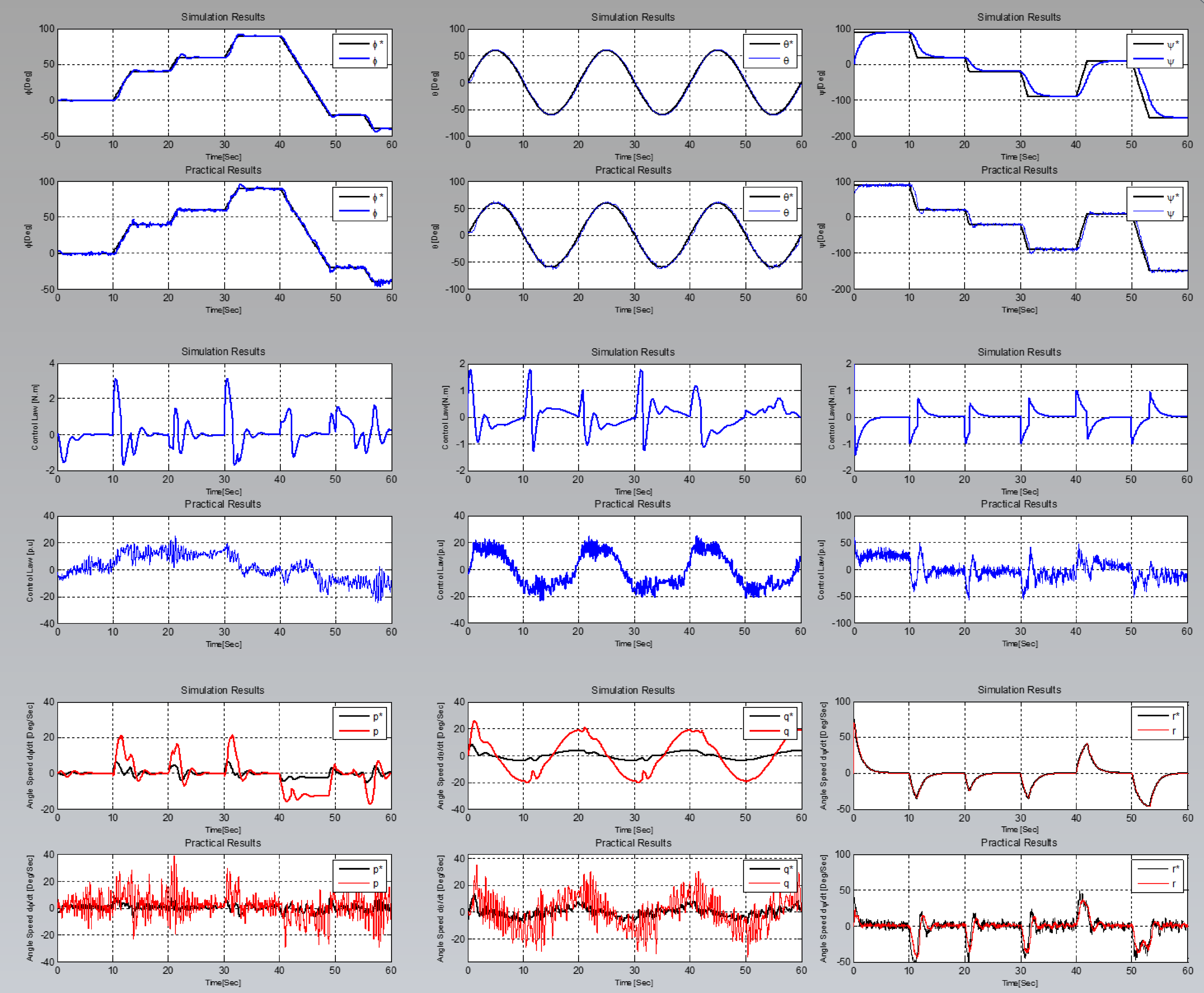
And the chosen structure of the integral LQR controller for roll and pitch is seen as follows where a feed forward loop has been added to obtain stabilization at steady state, which supports the control law to maintain the desired angle at its commanded value, and improve the system tracking response.



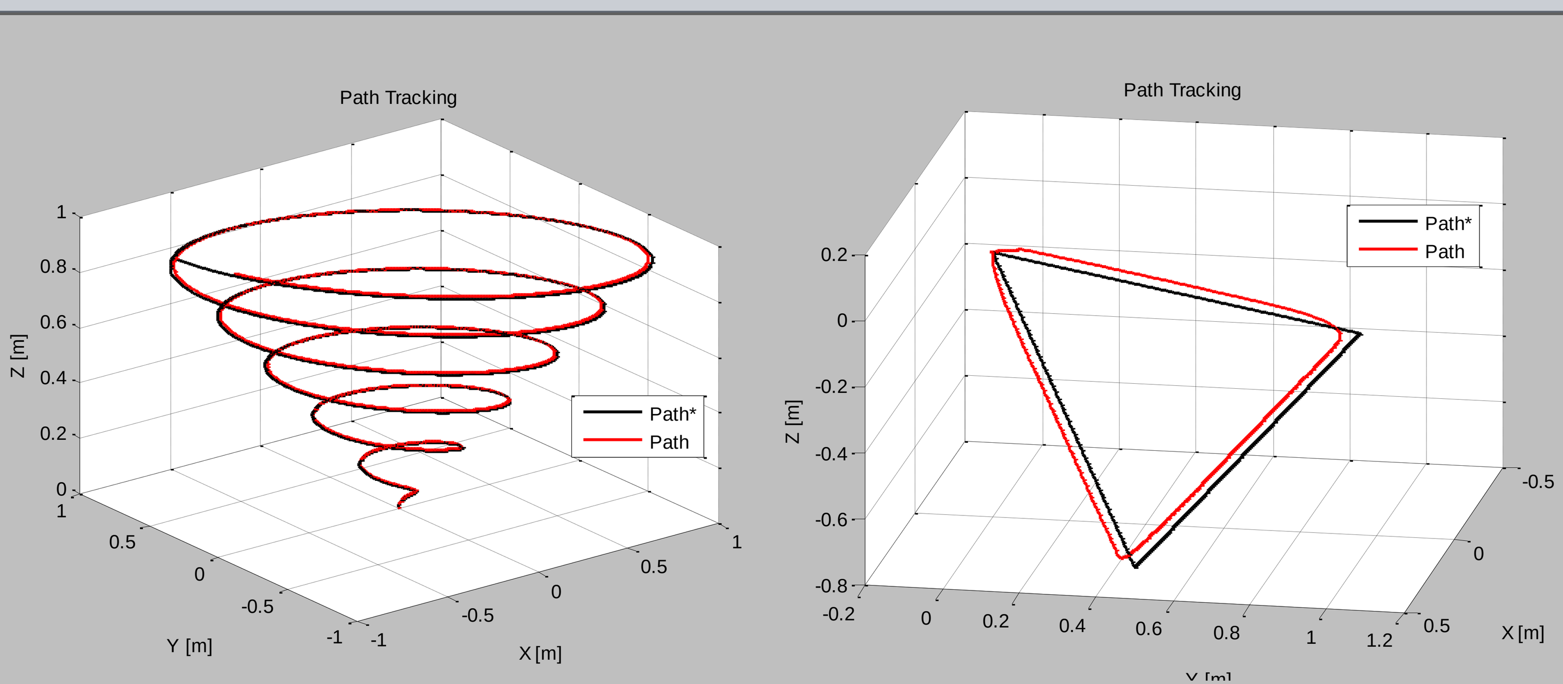
Different control approach structure was proposed for the yaw angle control



Practical Results



Simulation Results



Conclusion

In this poster, it has been presented a practical implementation of two LQR control loops for position control of the quadrocopter's body frame angles. It has been shown that the proposed control approach tracks fast the desired commands for roll, pitch and yaw angles in the body frame. It has been also noted that the proposed control approach, exhibits an inherited decoupling control action, for which the control of one axis angle has relieved the dynamic coupling effect on the other two axes. Furthermore, intensive practical results have demonstrated the robustness of the proposed controller. Future work is dedicated for the development of quadrocopter motion control on the Cartesian domain, which required an advance computer vision algorithm like SLAM to know the exact location of the vehicle in the coordinate system.

A part of this research has been published in the International Journal of Advanced Research in Artificial Intelligence (IJARAI), 2015. You can find the paper at the following link:

http://thesai.org/Publications/ViewPaper?Volume=4&Issue=5&Code=IJARAI&SerialNo=2

For further information, please do not hesitate to contact us.

Real-Time Control of Balancing Quadrocopter System

The figure on the right shows the test rig of the quadrocopter balancing control system. It has been completely developed by the graduate students in the integration of Mechatronics Systems Lab. As seen, the quadrocopter is linked with a four yellow straps. This is a safety procedure as the quadrocopter is running indoor. This method has no effect on the balancing system, as the system is due to work on the body frame angles control and has no motion with respect to the reference fixed earth frame.

References Available Upon Request.