Attitude Control of Radio-Controlled Helicopter

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Introduction

Helicopters have a very useful ability to hover.
Using hovering, They would be very suited for inspections and surveillance tasks.

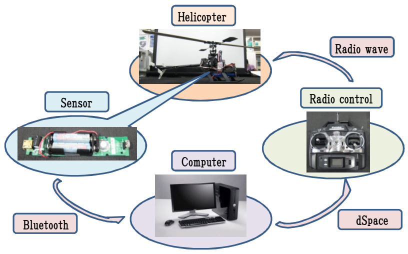
Ex)Inspection of power lines or buildings
Looking for fires in forests

Many researchers are studying with autonomous helicopter to expand in application.
In Japan, such as K.Nonami in Chiba University.

Outline

- Introduction
- **Experimental Circumstance**
  - Schematic of Controlling Helicopter
  - Information of Hardware
  - Calculation of attitude angle
  - Image of Wii controller's attitude angle
  - Transmit to radio control
  - Image of helicopter moving with Wii controller
- Analysis of helicopter model
  - Helicopter model
  - Calculation of helicopter dynamics transfer function
  - Identification of helicopter dynamics
  - Future plan

Schematic of Controlling Helicopter

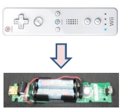


Helicopter : Controlled object
Sensor : Sensing attitude of helicopter
Computer : Computing control signals from the information of sensor
Radio control : Transmitting control signals

Information of Hardware

- Helicopter & Radio control
  EP Caliber 400 Produced by Kyosyo
  6EX-PCM Produced by Futaba
  To saving weight, getting rid of helicopter's decoration.

- Sensor
  Wii Controller Produced by Nintendo
  It has a gyro sensor and can transmit bluetooth signal.
  To saving weight, getting rid of outsider.
  The sensor fixed on the helicopter transmits information to the computer by bluetooth.



- Computer
  Receiver of the information of sensor
  USB-BT12 Produced by I-O DATA
  Sender of control signals to radio control
  DS1104 and harness

Calculation of attitude angle(1)

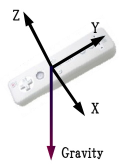
We can get Information of gyro sensor by using 'WiimoteLib'.
WiimoteLib is a free library of C# or VB,NET.

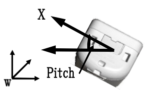
Information of gyro sensor have three components.

$$G = \begin{bmatrix} G_x \\ G_y \\ G_z \end{bmatrix}, \quad g = \sqrt{G_x^2 + G_y^2 + G_z^2}$$

$$\rightarrow \quad G' = \begin{bmatrix} G'_x \\ G'_y \\ G'_z \end{bmatrix}, \quad G'^2_x + G'^2_y + G'^2_z = 1$$

Using Rotation of world coordinate, **Roll, Pitch, Yaw angles** We can get equation about gyro information and attitude angles.





Calculation of attitude angle(2)

Define Roll angle as ψ, Pitch angle as θ, Yaw angle as ϕ.

$$\begin{bmatrix} G'_x \\ G'_y \\ G'_z \end{bmatrix} = \begin{pmatrix} c_\phi c_\theta & s_\phi c_\theta & -s_\theta \\ -s_\phi c_\psi + c_\phi s_\theta s_\psi & c_\phi c_\psi + s_\phi s_\theta s_\psi & c_\phi s_\psi \\ s_\phi s_\psi + c_\phi s_\theta c_\psi & -c_\phi s_\psi + s_\phi s_\theta c_\psi & c_\theta c_\psi \end{pmatrix} \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}$$

$$\rightarrow \begin{cases} G'_x = s_\theta \\ G'_y = -s_\phi c_\theta \\ G'_z = -c_\phi c_\theta \end{cases} \quad \therefore \theta = \sin^{-1}(G'_x) \;,\; \phi = -\sin^{-1}\left(\frac{G'_y}{\sqrt{1-G'^2_x}}\right)$$

Pitch $\rightarrow \theta = \sin^{-1}(G'_x)$, Yaw $\rightarrow \phi = -\sin^{-1}\left(\frac{G'_y}{\sqrt{1-G'^2_x}}\right)$

One gyro sensor can't recognize Roll angles.

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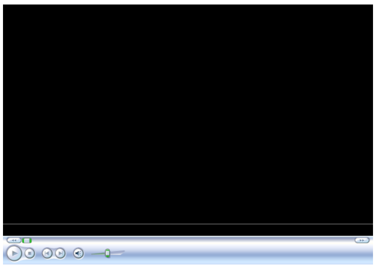
Image of Wii controller's attitude angle



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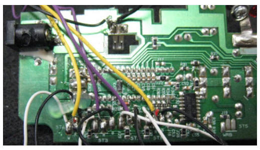
Transmit to radio control

To transmit control signals to radio control, connect computer and radio by dSpace and harness.
Radio control can measure degree of lever by potentiometer.

→ connecting harness to potentiometer output, we can control helicopter from computer.



Left figure is a close up of substrate connected harness.
Yellow and purple wire transmit current from computer.

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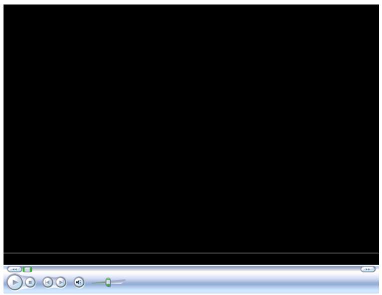
Image of helicopter moving with Wii controller



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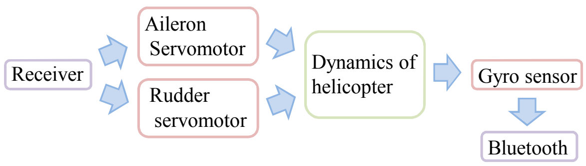
Helicopter model



To achieve attitude control, helicopter model can be interpreted to be shown upper figure.
Dynamics is classified dynamics of servomotor and helicopter.

→calculate each transfer function

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Calculation of helicopter dynamics transfer function(1)

Helicopter dynamics are constituted Pitch angle and Yaw angle. Pitch, Yaw motion are both generated gyroscopic precession of main rotor.

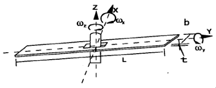
→both motions can describe same main rotor's motion equation.

Define main rotor's inertia moment of X axis, Y axis, Z axis as A_r, B_r, C_r

$$\rightarrow \begin{cases} A_r\dot{\omega}_x - (B_r - C_r)\omega_y\omega_z = L_r \\ B_r\dot{\omega}_y - (C_r - A_r)\omega_z\omega_x = M_r \\ C_r\dot{\omega}_z - (A_r - B_r)\omega_x\omega_y = N_r \end{cases} \quad (L_r, M_r, N_r : \text{rotation torque})$$

Suppose $\omega_z = \Omega$, and input Pitch angle signal $(M_r = N_r = 0)$,

$$\rightarrow \begin{cases} A_r\dot{\omega}_x - \Omega(B_r - C_r)\omega_y = L_r \\ B_r\dot{\omega}_y - \Omega(C_r - A_r)\omega_x = 0 \end{cases}$$



Calculation of helicopter dynamics transfer function(2)

$$B_r\dot{\omega}_y - \Omega(C_r - A_r)\omega_x = 0 \Leftrightarrow \dot{\omega}_x = \frac{B_r\ddot{\omega}_y}{\Omega(C_r - A_r)}$$

substitution

$$A_r\dot{\omega}_x - \Omega(B_r - C_r)\omega_y = L_r \rightarrow \ddot{\omega}_y - \frac{\Omega^2(C_r - A_r)(B_r - C_r)}{A_rB_r}\omega_y = L_r$$

Then, calculate Laplace transform of both sides

$$\ddot{\omega}_y - \frac{\Omega^2(C_r - A_r)(B_r - C_r)}{A_rB_r}\omega_y = L_r$$

$$s^2\Omega_y + \alpha\Omega_y = L_r \quad (\alpha = -\frac{\Omega^2(C_r - A_r)(B_r - C_r)}{A_rB_r}) \quad \Leftrightarrow \quad \Omega_y = \frac{1}{(s^2 + \alpha)}L_r$$

Pitch angle $\dot{\theta} = \omega_y$, $\Theta = \frac{1}{s(s^2 + \alpha)}L_r$

$$G_\theta = \frac{K_\theta}{s(T_\theta s^2 + 1)}, \quad G_\phi = \frac{K_\phi}{s(T_\phi s^2 + 1)}$$

Identification of helicopter dynamics

It is impossible to identify helicopter dynamics to input sine curve or M-sequence signal.
→input human operation
But it is important to take care to safety.

Identification method

- Halt condition
  Put helicopter on a rest
  Knot strings tight to helicopter's each side
- Flight condition
  Rest was taken off
  Strings go slack and helicopter can fly in some range
  If helicopter upsets the balance and start falling, string become tight and prevent falling

Future plans

Measuring servomotor frequency characteristic | Survey of helicopter model

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Calculation of servomotor and helicopter transfer function

↓

Identification of helicopter dynamics

↓

Simulation and determining Controller

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Testing