Helicopter Simulator

General Description

The system consists of a body, carrying propellers driven by DC motors, and a massive support. The body has two degrees of freedom. Both body position angles (elevation and azimuth) are influenced by rotation of propellers. The axes of a body rotation are perpendicular. DC motors are driven by power amplifiers using pulse width modulation. Both angles are measured by IRC sensors.

It is possible to modify the centre of gravity by moving small weight along the main horizontal axis of helicopter by a servomotor.

The mathematical model of the helicopter system is a typical MIMO 2×2 system with significant cross-couplings.

Figure 1: The helicopter model Humusoft CE 150.

Mathematical Model

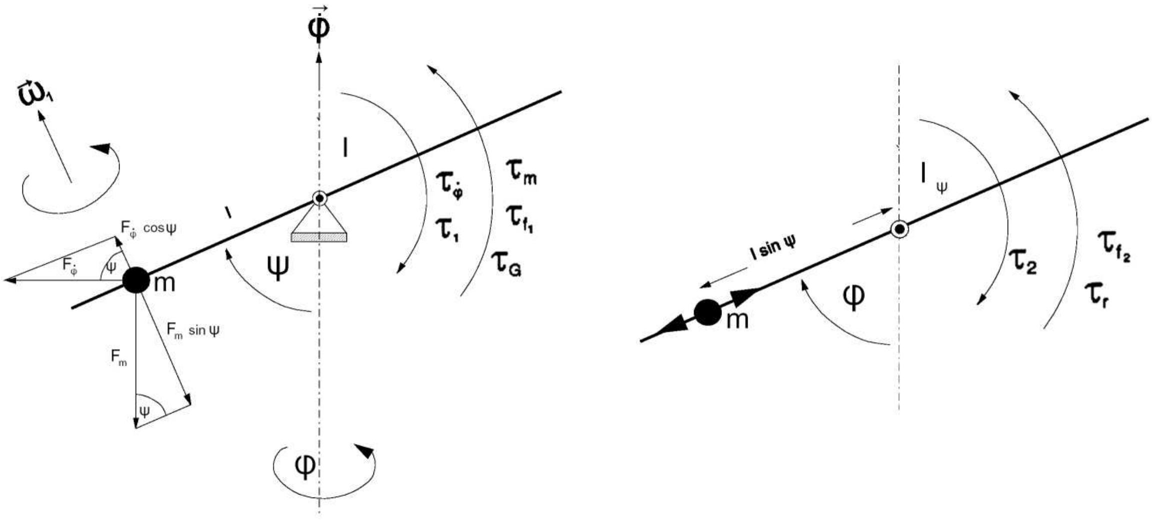

Figure 2: Torques action on the body in the vertical and horizontal planes.

Elevation dynamics

The torque balance regarding the elevation (pitch) dynamics is as follows:

$$\tau_1 + \tau_{\dot{\phi}} - \tau_{f_1} - \tau_m - \tau_G = I\ddot{\psi}$$

I = moment of inertia $[Kg \cdot m^2]$

ψ = elevation angle (pitch) $[rad]$

τ_1 = main motor driving torque $[N \cdot m]$

$\tau_{\dot{\phi}}$ = centrifugal torque $[N \cdot m]$

τ_{f_1} = friction torque $[N \cdot m]$

τ_m = gravitational torque $[N \cdot m]$

τ_G = gyroscopic torque $[N \cdot m]$

Azimuth dynamics modeling

The torque balance regarding the azimuth (yaw) dynamics is as follows:

$$\tau_2 - \tau_{f_2} - \tau_r = I_\psi \ddot{\phi}$$

I_ψ = moment of inertia (depends on elevation) $[Kg \cdot m^2]$

ϕ = azimuth angle (yaw) $[rad]$

τ_2 = stabilizing motor driving torque $[N \cdot m]$

τ_{f_2} = friction torque $[N \cdot m]$

τ_r = main motor reaction torque $[N \cdot m]$

DC motor and propeller dynamics modeling

Dynamics of the DC motors and propellers can be approximated as follows:

$$\tau_1 = K_{\omega_1}\,\omega_1^2\,sign(\omega_1)$$

$$\tau_2 = K_{\omega_2}\,\omega_2^2\,sign(\omega_2)$$

ω_1 = angular velocity of the main propeller $[rad/s]$
ω_2 = angular velocity of the stabilizing propeller $[rad/s]$

Sensor and power amplifier modeling

Since incremental encoders are used for angle measurements, they can be considered with no dynamics.

$$y_\psi = k_\psi\,\psi$$

$$y_\phi = k_\phi\,\phi$$

y_ψ = elevation angle [deg]
y_ϕ = azimuth angle [deg].

Regarding the power amplifiers, they can be considered as ideal, that is

$$u_a = K\,u$$

where MU denotes *machine units*, which interval is [-1, 1].
u = computer command $[MU]$
u_a = armature voltage $[V]$

Complete model

The complete model of the helicopter simulator is reported in Fig. 3.

Empirical (simplified) model

A simplified model is reported in Fig. 4. Since the parameters of this model has been identified (see Table 1), this model can be used as a simulator of the real process.
Note that this model has 2 inputs and 2 outputs.
- Inputs are the motor commands in machine units MU.
- Outputs are the elevation and the azimuth angles in degrees.

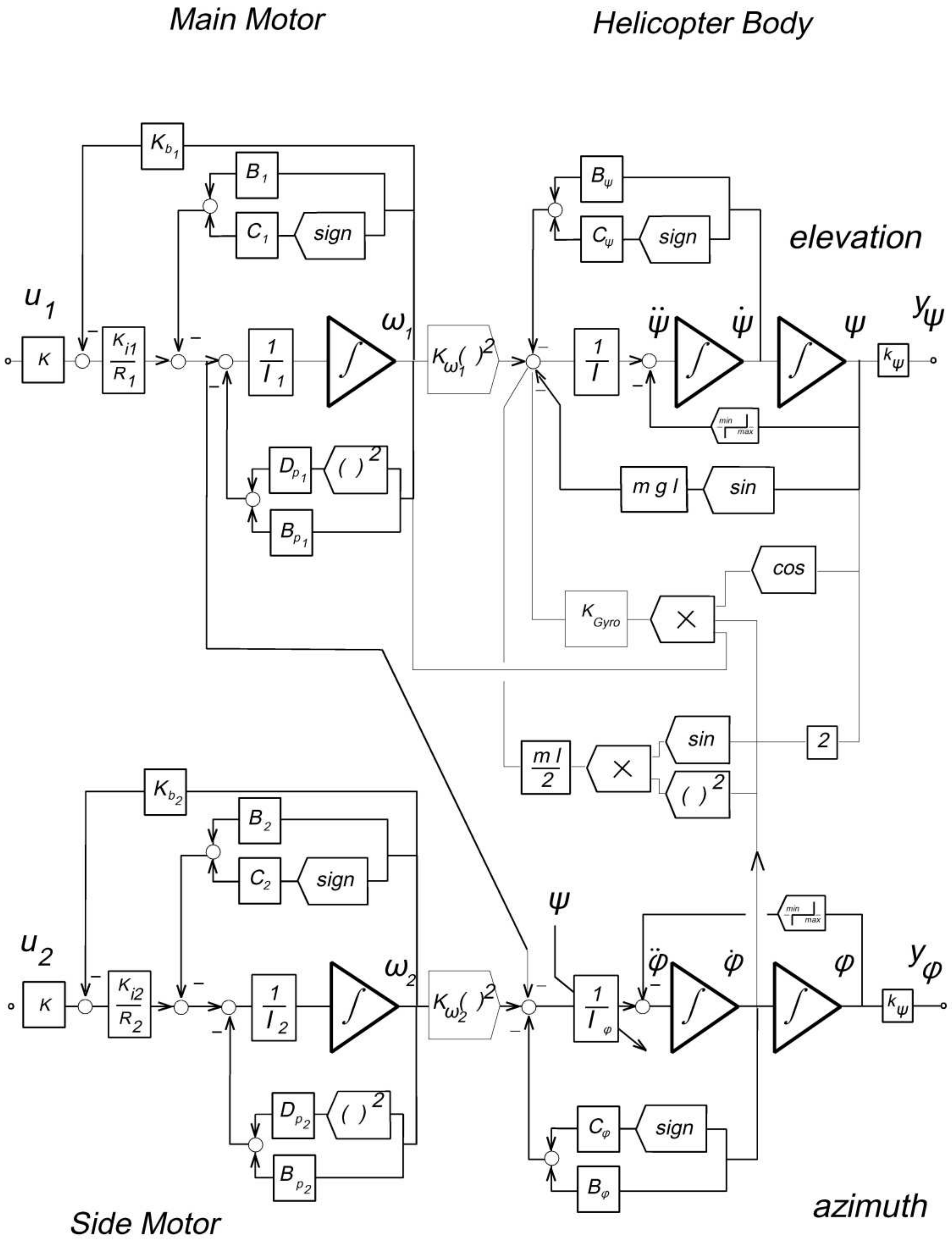

Figure 3: The complete model of the helicopter simulator.

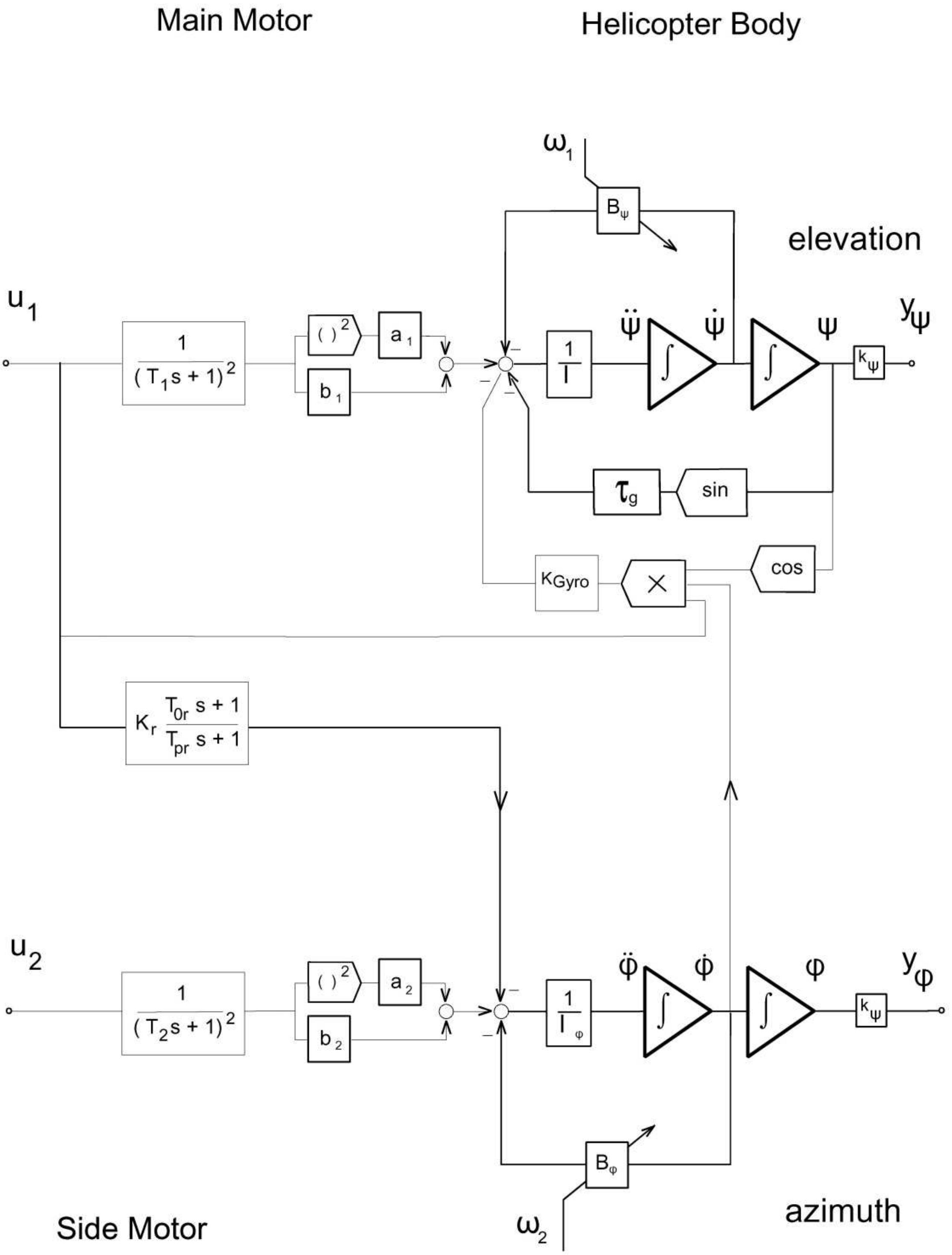

Figure 4: The empirical (simplified) model of the helicopter simulator.

Identified values of the empirical model parameters

In Table 1 the values of the empirical model parameters are reported. These values has been obtained both by the helicopter manual and by an identification experiment.

Var.	**Value**	**Units**
k_ψ	$180/\pi$	$[MU/rad]$
k_ϕ	$180/\pi$	$[MU/rad]$
τ_g	$3.83 \cdot 10^{-2}$	$[N \cdot m]$
a_1	0.186	$[N \cdot m/MU^2]$
b_1	-0.0445	$[N \cdot m/MU]$
a_2	0.033	$[N \cdot m/MU^2]$
b_2	0.0294	$[N \cdot m/MU]$
B_ψ	$5 \cdot 10^{-3}$	$[Kg \cdot m^2/s]$
I	$4.37 \cdot 10^{-3}$	$[Kg \cdot m^2]$
B_ϕ	$8.69 \cdot 10^{-3}$	$[Kg \cdot m^2/s]$
I_ϕ	$4.14 \cdot 10^{-3}$	$[Kg \cdot m^2]$
T_1	0.1	$[s]$
T_2	0.25	$[s]$
K_r	-0.00891	$[N \cdot m/MU]$
T_{0r}	2.7	$[s]$
T_{pr}	0.75	$[s]$
K_{Gyro}	0.015	$[N \cdot m/s]$

Table 1: Values of the parameters of the empirical model.