

Errata

- On page xx, line two,
“Lennart Ljung, Wei Lin, Rogelio Lozano, David Mayne, Iven Mareels” should be
“Wei Lin, Lennart Ljung, Rogelio Lozano, Iven Mareels, David Mayne”.
- On page 30, the line after (1.138), “of (1.135)” should be “of (1.135):”.
- On page 31, line 1, it should be “(i.e., $r(s) = \frac{1}{s}$)”.
- On page 32, line 12, “efficiently” should be “effectively”.
- On page 34, line 3, change “ $a = -5$ ” to “ $a_p = 5$ ”.
- On page 37, in (2.10), change “ $\Phi(t, t_0) = e^{A(t-t_0)} = L^{-1} [(sI - A)^{-1}]$ ” to

$$\Phi(t, t_0) = e^{A(t-t_0)}, e^{At} = L^{-1} [(sI - A)^{-1}].$$
- On page 38, after (2.15), “ $\int_{t_0}^t D(t)\delta(t - \tau)u(\tau)dt = D(t)u(t)$ ” should be “ $\int_{t_0}^t D(t)\delta(t - \tau)u(\tau)d\tau = D(t)u(t)$ ”.
- On page 43, in (2.36), “ $G_0(s)$ ” should be “ $G(s)$ ”.
- On page 46, in (2.50), “ k_1 ” and “ k_2 ” should be “ c_1 ” and “ c_2 ”.
- On page 52, in Definition 2.11, “ $\|x(t; x_0, t_0)\| < k(\beta)e^{-\alpha(t-t_0)}, \forall t \geq t_0.$ ” should be “ $\|x(t; x_0, t_0)\| < k(\beta)\|x_0\|e^{-\alpha(t-t_0)}, \forall t \geq t_0.$ ”
- On page 54, to use the given choices of $\phi(r)$ for Definitions 2.17e, 2.19e and 2.20e, the property (ii) of the class- \bar{K} functions should be replaced by (ii') $\phi(r_1) \leq \phi(r_2), \forall r_1 \leq r_2$ (i.e., $\phi(\cdot)$ is a monotonically increasing function but not strictly monotonically increasing), leading to a different definition of the class- \bar{K} functions [351, page 107], [426, 1st edition (1978)].
 With the given (and popular in the literature) definition of the class- \bar{K} functions (i.e., $\phi(\cdot)$ strictly monotonically increasing), the equivalence of Definition 2.17 and Definition 2.17e follows from the fact that there exists a class- \bar{K} function $\phi(r)$ such that $\phi(r) \leq \inf_{r \leq \|x\| \leq h} W(x)$ [179, 3rd edition (2003)], [426]. The equivalence of Definition 2.19 and Definition 2.19e follows from the fact that there exists a class- \bar{K} function $\phi(r)$ such that $\phi(r) \leq \inf_{r \leq \|x\|} W(x)$. The equivalence of Definition 2.20 and Definition 2.20e follows from that fact that there exists a class- \bar{K} function $\phi(r)$ such that $\phi(r) \geq \sup_{\|x\| \leq r} W(x)$. Such functions $\phi(r)$ can be constructed based on $\inf_{r \leq \|x\| \leq h} W(x)$, $\inf_{r \leq \|x\|} W(x)$, and $\sup_{\|x\| \leq r} W(x)$, respectively [259], [426].
- On page 56, line 18 and line 19, change “(ii) $\phi(r_1) < \phi(r_2)$, for any $0 \leq r_1 < r_2 \leq h$; and $\phi(\|x\|) \leq W(x), \forall x \in B(h)$ ” to “(ii) $\phi(r_1) \leq \phi(r_2)$, for any $0 \leq r_1 \leq r_2 \leq h$; and (iii) $\phi(\|x\|) \leq W(x), \forall x \in B(h)$ ”.
- On page 57, line 7, “ $\frac{dW(x(t))}{dt}$ ” should be “ $\frac{dW(x(t))}{dt}$ ”.
- On page 57, 5 lines above (2.84), add “}” to close up $B(h)$.

- On page 69, in (2.131), replace “=” by “≤”.
- On page 71, last line of (2.139), “ $\leq e^{-\delta t} \|h_\delta(\cdot)\|_1 \int_0^t e^{\delta \tau} |x_2(\tau)| d\tau = \dots$ ” should be

$$\leq e^{-\delta t} \|h_\delta(\cdot)\|_1 \int_0^t e^{\delta \tau} |x_2(\tau)| d\tau = \dots”.$$

- page 78, under “Definition 2.25”, “ $h_s(s) = \frac{R+sC}{sCR}$ ” should be “ $h_s(s) = \frac{RCs+1}{sC}$ ”, and “ $H_s(s) = \frac{R}{sC+R}$ ” should be “ $H_s(s) = \frac{R}{sRC+1}$ ”.

- On page 78, Lemma 2.10, (iii), the last part “or $\lim_{\omega \rightarrow \infty} \frac{h(j\omega)}{j\omega} > 0$ if $n^* = -1$ ” should be “or $\lim_{\omega \rightarrow \infty} \operatorname{Re}[h(j\omega)] > 0$ and $\lim_{\omega \rightarrow \infty} \frac{h(j\omega)}{j\omega} > 0$ if $n^* = -1$ ” (as given in [152]).

Or, the last two parts “or $\lim_{\omega \rightarrow \infty} \operatorname{Re}[h(j\omega)] > 0$ if $n^* = 0$, or $\lim_{\omega \rightarrow \infty} \frac{h(j\omega)}{j\omega} > 0$ if $n^* = -1$ ” is replaced by “or $\lim_{\omega \rightarrow \infty} \operatorname{Re}[h(j\omega)] > 0$ and $\lim_{\omega \rightarrow \infty} \frac{h(j\omega)}{j\omega} > 0$ if $n^* = -1$ ”; that is, the case of $n^* = 0$ is excluded from (iii), as the result for $n^* = 0$ follows from (ii), by the continuity of $h(s)$ (for $h(s) = c(sI - A)^{-1}b + d$ with $d \neq 0$, if $\operatorname{Re}[h(j\omega)] > 0$ for all $\omega \in (-\infty, +\infty)$, then $d > 0$).

- On page 81, line 5, delete the word “scalar”.
- On page 83, in (2.187), “ $f(0)$ ” should be “ $g(0)$ ”.
- On page 83, in Lemma 2.19, “ $\lim_{t \rightarrow \infty} f(t) = 0$ ” should be “ $\lim_{t \rightarrow \infty} g(t) = 0$ ”.
- On page 85, equation (2.200) should be

$$\Phi(t, t_0) = A^{t-t_0} = \underbrace{AA \cdots A}_{i-i_0}, t \geq t_0.$$

- On page 96, in Problem 2.7, change “uniformly” to “(uniformly)”.
- On page 101, above (3.15), “ $\omega_1(t) \in R^n, \omega_1(t) \in R^n$ ” should be “ $\omega_1(t) \in R^n, \omega_2(t) \in R^n$ ”.
- On page 106, in line 6, delete “ \geq ” from “ $z^T P(t_0)z \geq$ ”.
- On page 107, in (3.45), the choice of the normalizing term $m(t) > 0$ is arbitrary at this point, while the choice of $m(t)$ in (3.32) is a desired one.
- On page 109, in line 11 (Theorem 3.1), change “ C^n ” to “ C^{n+m+1} ”.
- On page 109, in line 26 (Proposition 3.1), change “ C^n ” to “ C^{n+m+1} ”.
- On page 110, in line 5, “Then, we can define $\varepsilon(t) = \theta(t)\phi(t)$ ” should be “Then, we can define $\varepsilon(t) = \theta(t)\phi(t) - \bar{y}(t)$ ”.
- On page 110, in Lemma 3.3, change “ α_0 ” to “ α_s ” (as a notation, different from α_0 in (3.52)).
- On page 111, at the end of the proof of Lemma 3.3, add “ $\alpha_s = \sqrt{1 - \lambda_s}$ ”.
- On page 120, in line 17 (Theorem 3.2), change “ C^n ” to “ C^{n+m+1} ”.
- On page 120, in line 27 (Proposition 3.2), change “ C^n ” to “ C^{n+m+1} ”.

- On page 132, in (3.177), “ $\tilde{\theta}^T(t)\Gamma f(t)$ ” should be “ $\tilde{\theta}^T(t)\Gamma^{-1}f(t)$ ”.
- On page 155, in line 1 and line 2, change “(motor voltage)” by “(motor torque generated by armature current)” and change “joint force” to “joint torque”.
- On page 156, Assumption (A4.4) implies Assumption (A4.3) (because, with $P(s) = \det(sI - A)$, any possible pole-zero cancellation in $G(s)$ is stable if $Z(s)$ is stable).
- On page 157, in (4.44), “ $P_m(s)Z(s)\frac{1}{k_p}$ ” should be “ $P_m(s)Z(s)$ ”.
- On page 160, after (4.68), “ $k_{3j}^* = d_j$ ” to “ $k_{3j}^* = -d_j$ ”.
- On page 161, for Section 4.3.2, the vectors B and B_d in (4.79) are not assumed to be parallel to each other, i.e., they can be independent.

On page 162, for (4.93), the coefficients of cos terms are in general not zero (and thus need to be estimated for implementing the controller (4.92)) seven if the coefficients of the cos terms in (4.90) and (4.91) are zero. If both d_{u0} and d_{y0} in (4.90) and (4.91) are zero, then k_{30}^* in (4.93) is zero and its estimate $k_{30}(t)$ in (4.92) can be set to be zero.

- On page 170, in Lemma 4.2, “(4.93) and (4.94)” should be “(4.130) and (4.131)”.
- On page 175, equation (4.159) should be

$$\rho^* = b_p, \theta^* = [k_1^*, k_2^*]^T, \theta = [k_1, k_2]^T$$

- On page 178, Assumption (A4.4-D) implies Assumption (A4.3-D).
- On page 207, in (5.72), the parameter “ a ” is different from the polynomial vector “ $a(s)$ ” in (5.6)–(5.7) on page 197.
- On page 215, line 10, “(5.119)” should be “(5.118)”.
- On page 233, the first inequality of equation (5.207) should be

$$\int_{t_1}^{t_2} e^2(t) dt \leq \frac{1}{a_m} (V(e_p(t_1)) - V(e_p(t_2))) + \int_{t_1}^{t_2} \frac{d^2(t)}{a_m^2} dt$$

- On page 241, before (5.244), “(5.223)” should be “(5.233)”.
- On page 241, in (5.247), $\pi(z(t))$ should be

$$\begin{aligned} \pi(z(t)) = & V(e(0), \tilde{\theta}(0)) + 2z(t)(-|b_p| + 2b_p \sin z(t)) + 4b_p \cos z(t) - 2b_p z^2(t) \cos z(t) \\ & - 2z_0(-|b_p| + 2b_p \sin z_0) - 4b_p \cos z_0 + 2b_p z_0^2 \cos z_0 \end{aligned}$$

- On page 264, lines 5 and 6, “ $i = 1, 2, \dots, l''$ ” should be “ $i = 1, 2, \dots, l'$ ”.
- On page 274, after (6.15), “ $\bar{\theta}^*$ ” should be “ $\bar{\theta}^*$ ”.
- On page 278, line 8, “adaptive law for $\theta(t)$ ” should be “adaptive laws for $\theta(t)$ and $\rho(t)$ ”.
- On page 279, in Theorem 6.2, “ $W_m(z) = z^{n^*}$ ” should be “ $W_m(z) = z^{-n^*}$ ”.

- On page 279, in (6.57), “ $Z(z)$ ” should be “ $k_p Z(z)$ ”.
- On page 288, equation (6.121) should be

$$\phi(t) = [u(t-n^*), \dots, u(t-n^*-n+1), \\ y(t-n^*), \dots, y(t-n^*-n+1)]^T.$$

- On page 305, in (7.75), delete “or if $\theta_{pm+1}(t) = \theta_{pm+1}^b, g_{m+1}(t) \leq 0$ ”.
- On page 311, after the last sentence, add “In particular, (5.137) is to be used to derive a counterpart of (5.141) based on which the closed-loop signal boundedness can be concluded. To establish (5.137), the condition that all zeros of $Z(s)$ are stable is crucial (see (5.135) where $G_0^{-1}(s) = \frac{P(s)}{k_p Z(s)}$ is present), when $\theta(t)$ is bounded.”
- On page 316, (7.146) should be

$$\Psi_1 = - \begin{bmatrix} \psi_c & 0 & \cdots & 0 & 0 \\ 1 & \psi_c & \cdots & \vdots & 0 \\ 0 & 1 & \cdots & 0 & \vdots \\ \vdots & 0 & \cdots & 0 & 0 \\ 0 & \vdots & \cdots & 0 & 0 \\ 0 & 0 & \cdots & \psi_c & 0 \\ 0 & 0 & \cdots & 1 & \psi_c \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ \vdots \\ q_{n_q-1} \\ 1 \end{bmatrix} + \begin{bmatrix} \lambda_0^c \\ \lambda_1^c \\ \vdots \\ \lambda_{n_q+n-2}^c \end{bmatrix}$$

and (7.147) should be

$$\Psi_2 = - \begin{bmatrix} d_0 \\ d_1 \\ \vdots \\ d_{n_q+n-2} \end{bmatrix} + d_{n_q+n-1} \begin{bmatrix} \lambda_0^c \\ \lambda_1^c \\ \vdots \\ \lambda_{n_q+n-3}^c \\ \lambda_{n_q+n-2}^c \end{bmatrix}.$$

- On page 320, equation (7.172) should be

$$\hat{\theta}_{qp}(t) = [1, \hat{p}_{n+n_q-1}, \hat{p}_{n+n_q-2}, \dots, \hat{p}_1, \hat{p}_0]^T \in R^{n+n_q+1}$$

and equation (7.175) should be

$$\hat{\theta}_d(t) = [\hat{d}_{n+n_q-1}, \hat{d}_{n+n_q-2}, \dots, \hat{d}_1, \hat{d}_0]^T \in R^{n+n_q}.$$

- One page 330, in (7.227), “ $k_1(t) = \frac{-\hat{a}_p(t)-a_m}{\hat{b}_p(t)}$ ” should be “ $k_1(t) = \frac{-\hat{a}_p(t)+a_m}{\hat{b}_p(t)}$ ”.
- On page 346, in line 4, 8, 12, 21, 22, 25, “ $p_d(D)$ ” should be “ $P_d(D)$ ”.
- On page 348, in part (iv) of Problem 7.11, change “Problem 5.1” to “Problem 5.3”.
- On page 367, above (8.109), “ $\hat{\beta}$ is the estimate of β ” should be “where $\hat{\beta}_1$ is the estimate of β_1 ”.

- On page 368, in (8.120), “ $-\gamma_0$ ” should be “ γ_0 ”.
- On page 369, in (8.125), “ $\dot{V}_3(t)$ ” should be “ \dot{V}_3 ”, and “ $c_5 z_3 x_4^4$ ” should “ $c_5 z_3^2 x_4^4$ ”.
- On page 378, line 3, “ $y(t)$ ” should be “ $x(t)$ ”.
- On page 380, in (9.50), “ $r(t)$ ” should be “ $u(t)$ ”; line 19, “ $y_m(t)$ ” should be “ $x_m(t)$ ”; line 20, “ $e(t) = x(t) - x_m(t)$ ” should be “ $e(t) = x_m(t) - x(t)$ ”.
- On page 393, above (9.106), “(9.102)” should be “(9.105)”.
- On page 393, in (9.106), “ I ” should be “ I_M ”.
- On page 395, after (9.113), “if all finite poles of ...” should be “as all finite poles of ...”.
- On page 408, in (9.180C), “ $\beta(\zeta^T \zeta + \xi^T \xi)$ ” should be “ $\varepsilon \beta(\zeta^T \zeta + \xi^T \xi)$ ”.
- On page 410, in (9.174D), “ $\beta(\zeta^T \zeta + \xi^T \xi)$ ” should be “ $\varepsilon \beta(\zeta^T \zeta + \xi^T \xi)$ ”.
- On page 443, under (9.357), “ U ” should be “ U_s ”.
- On page 448, in (9.389), “ $\Phi_i = U \Theta_i$ ” should be “ $\Phi_i^{*T} = U \Theta_i^{*T}$ ”.
- On page 451, in line 1, “(9.397)” should be “(9.395)”.
- On page 454, (9.397) should be

$$\bar{e}(t) = SD_s h(D) \left[[\tilde{\Phi}_1^T \chi_1, \tilde{\Phi}_2^T \chi_2, \dots, \tilde{\Phi}_M^T \chi_M]^T \right] (t).$$

- On page 455, under (9.433), “ $i = 2, 3, \dots, M$ ” should be “ $i = 1, 2, \dots, M$ ”.
- On page 463, in the second line after (9.486), “ ${}_m B_m = (S_m B_m)^T > 0$ ” should be “ $S_m B_m = (S_m B_m)^T > 0$ ”.
- One page 483, (9.606) should be

$$u(t) = Y(q, q_d, \dot{q}, \dot{q}_d, \ddot{q}_d, t) \theta^*(t) + \frac{1}{2} \frac{\partial D(q, t)}{\partial t} (\dot{q} + v) - K_D s.$$

Note that this control law leads the time derivative of $V(s, \tilde{\theta}, t) = \frac{1}{2} s^T D(q(t), t) s$ to $\dot{V} = -s^T K_D s$.

- On page 483, (9.608) should be

$$m(t) = k_0 \|\dot{q}(t) + v(t)\| f(q), \quad k_0 > 0, \quad \psi(t) = m(t) s(t).$$

- On page 494, below (9.655), “ $\varepsilon(t) = \tilde{\Theta}^T(t) \zeta(t)$ ” should be “ $\varepsilon(t) = \tilde{\Theta}^T(t) \zeta(t)$ ”; also in (9.656), “ ζ ” should be “ ζ ”.

To see (9.655), we derive $\tilde{\Theta}^T(t) f(D) [\zeta](t) = \tilde{\Theta}^T(t) \omega(t) + \tilde{\Theta}_3(t) (\xi_m(D) [y](t) - r(t)) = \Theta_3(t) \xi_m(D) [y - y_m](t)$, here the identity $\tilde{\Theta}^T(t) \omega(t) = \Theta_3^* \xi_m(D) [y] - y_m(t)$ has been used.

- On page 494, above (9.657), “(9.468)” should be “(9.366)”.
- On page 526, after (10.109), “ $u_d(t) = [u_{d1}(t), \dots, u_{dm}(t)]^T$ ” and “ $\widehat{NI}(\cdot) = [\widehat{NI}_1(\cdot), \dots, \widehat{NI}_m(\cdot)]^T$ ” should be “ $u_d(t) = [u_{d1}(t), \dots, u_{dM}(t)]^T$ ” and “ $\widehat{NI}(\cdot) = [\widehat{NI}_1(\cdot), \dots, \widehat{NI}_M(\cdot)]^T$ ”.

- On page 528, in (10.134), “ $\sum_{i=1}^m$ ” should be “ $\sum_{i=1}^M$ ”.
- On page 529, in (10.140) and (10.141), “ $\omega_1(t)$ ” should be “ $\psi_1(t)$ ”, and “ $\omega_2(t)$ ” should be “ $\psi_2(t)$ ”.
- On page 530, after (10.148), ϕ_4^* should be “ $\phi_4^* = -\phi_1^* \otimes \theta^* \triangleq -[\phi_{11}^* \theta^{*T}, \phi_{21}^* \theta^{*T}, \dots, \phi_{1n-1}^* \theta^{*T}]^T \in R^{(n-1)n_\theta}$ ”.
- On page 531, after (10.155), “and $d(t)$ is as in (10.77)” should be “and $d(t)$ is as in (10.77) with $W(D)$ in (10.87)”.
- On page 533, in (10.170), “ $d(t)$ ” should be “ $d_N(t)$ ”.
- On page 534, in line 5, “ x ” should be “ x_m ”; in (10.171), “ s ” should be “ D ”; in (10.173), “ $\omega_1(t)$ ” should be “ $\phi_1(t)$ ”; in (10.176), “ $\omega_4(t)$ ” should be “ $\phi_4(t)$ ”, “ $\omega_2(t)$ ” should be “ $\phi_2(t)$ ”, and “ Φ^3 ” should be “ Φ_3 ”.
- On page 538, before (10.194), “ $\alpha(x)^{-1}$ ” should be “ $\alpha^{-1}(x)$ ”.
- On page 556, (10.288) should be

$$\omega_{m2}(t) = \frac{(s^{m+1} + k_1 s^m) I_4}{s^n + k_1 s^{n-1} + \dots + k_{n-1} s + k_n} [\sigma(y)\omega](t) \quad (n - m = \rho \geq 2).$$

(Note that for the case of $n - m = 1$, $\omega_{m2}(t) = \frac{-(k_2 s^{n-2} + k_3 s^{n-3} + \dots + k_{n-1} s + k_n) I_4}{s^n + k_1 s^{n-1} + \dots + k_{n-1} s + k_n} [\sigma(y)\omega](t)$, and no derivative of $\omega_{i2}(t)$, $i = 0, 1, \dots, m$, is needed in the backstepping design procedure.)