Adaptive Control Design and Analysis

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 “$\Phi(t,t_0) = e^{A(t-t_0)} = L^{-1} \left[ (sI - A)^{-1} \right]$” to
  \[ \Phi(t,t_0) = e^{A(t-t_0)}, \quad e^{A} = L^{-1} \left[ (sI - A)^{-1} \right]. \]

- On page 38, after (2.15), “$\int_{t_0}^{t} D(t) \delta(t-\tau) u(\tau) d\tau = D(t) u(t)$” 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 47, line 2, “$A(t) \in \mathbb{R}^{n \times n}$” should be “$A(t) \in \mathbb{R}^{m \times n}$”.

- 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-$\mathcal{K}$ 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-$\mathcal{K}$ functions [351, page 107], [426, 1st edition (1978)].

With the given (and popular in the literature) definition of the class-$\mathcal{K}$ 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-$\mathcal{K}$ function $\phi(r)$ such that $\phi(r) \leq \inf_{\|x\| \leq h} W(x)$ [179, 3rd edition (2003)], [426]. The equivalence of Definition 2.19 and Definition 2.19e follows from the fact that there exists a class-$\mathcal{K}$ function $\phi(r)$ such that $\phi(r) \leq \inf_{\|x\| \leq h} W(x)$. The equivalence of Definition 2.20 and Definition 2.20e follows from the fact that there exists a class-$\mathcal{K}$ function $\phi(r)$ such that $\phi(r) \geq \sup_{\|x\| \leq r} W(x)$. Such functions $\phi(r)$ can be constructed based on $\inf_{\|x\| \leq h} W(x)$, $\inf_{\|x\| \leq \|x\|} W(x)$, 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 85, equation (2.200) should be

\[ \leq e^{-\delta \|h_\delta(x)\|_1} \int_0^1 e^{\delta \tau} |x_2(\tau)| d\tau = \ldots \]

On page 83, in Lemma 2.19, "lim \( \alpha \rightarrow \infty \) \( h(j\omega) \) > 0 if \( n^* = -1 \)" should be

On page 110, in Lemma 3.3, change "\( \lim \)" to "\( \rightarrow \)".

On page 81, line 5, delete the word "scalar".

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 \( \theta(T \phi(t)) \)" should be "Then, we can define \( \theta(T \phi(t) - \tilde{y}(t)) \)".

On page 11, at the end of the proof of Lemma 3.3, add "\( \alpha_s = \sqrt{1 - \kappa_s} \)".
• 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).

In (4.44), the closed-loop poles are the zeros of $P_m(s)$ and $Z(s)$, so that $Z(s)$ has to be stable, which implies that $(A, B, C)$ needs to be stabilizable and detectable.
• 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), “$k^*_3 j = d_j$” to “$k^*_3 j = -d_j$”.
• 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 165, in (4.100), the time variable “t” is missing in those sin and cos signals.
• On page 170, in Lemma 4.2, “(4.93) and (4.94)” should be “(4.130) and (4.131)”.
• On page 170, in line 8, “Parametrization of State Feedback” should be “Parametrization of Observer-Based Feedback”.

In line 17, “using an estimate of $k^*_1 x(t)$ which needs” should be “using an estimate of $k^*_1 x(t)$, which needs”.
• 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 185, in (4.222), the time variable “t” is missing in those sin and cos signals.
• On page 188, in line 6, “Parametrizations of State Feedback” should be “Parametrization of Observer-Based Feedback”.

In line 15, “using an estimate of $k^*_1 x(t)$ which” should be “using an estimate of $k^*_1 x(t)$, which”.
• On page 200, line 1, if the original plant is described by: $P(s)C(s)[y](t) = k_p Z(s)C(s)[u](t)$, for some polynomial $C(s)$, we can still obtain (5.28) but (5.29) should be operated by $C(s)$. Then, to reach (5.30), $C(s)$ needs to be stable. Hence, for MRAC, the original state-space form $(A_0, B_0, C_0)$ of (5.1) needs to be stabilizable and detectable.
• 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

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

• On page 241, before (5.244), “(5.223)” should be “(5.233)”.

• On page 241, in (5.247), \( \pi(z(t)) \) should be

\[ \pi(z(t)) = V(e(0), \theta(0)) + 2z(t)(-|b_p| + 2b_p \sin z(t)) + 4b_p \cos z(t) - 2b_p z^2(t) \cos z(t) \]

\[ -2z_0(-|b_p| + 2b_p \sin z_0) - 4b_p \cos z_0 + 2b_p z^2_0 \cos z_0 \]

• On page 246, 5 lines below (5.344), “However, with (5.342), it has not been concluded” should be “With (5.342) and (5.159), since \( \lim_{t \to \infty} d(t) = 0 \), it can be concluded that \( \lim_{t \to \infty} (y(t) - y_m(t)) = 0 \). However, for adaptive control with parameter estimates \( \theta_i(t) \), it has not been concluded”.

• On page 264, lines 5 and 6, “\( i = 1, 2, \ldots, l'' \) should be “\( i = 1, 2, \ldots, l'' \).

• On page 265, line 8, “part (i)” should be “part (iii)”.

• On page 274, after (6.15), “\( \bar{\theta}^* \)” should be “\( \tilde{\theta}^* \)”.

• 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

\[ \phi(t) = \begin{bmatrix} u(t-n^*), & \ldots, & u(t-n^*-n+1), \\ y(t-n^*), & \ldots, & y(t-n^*-n+1) \end{bmatrix} \]

• 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 \( G_0^{-1}(s) = \frac{P(s)}{k_pZ(s)} \) 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

\[
\Psi_2 = - \begin{bmatrix}
  d_0 \\
  d_1 \\
  \vdots \\
  d_{n_q+n-2}
\end{bmatrix} + d_{n_q+n-1} + \begin{bmatrix}
  \lambda^c_0 \\
  \lambda^c_1 \\
  \vdots \\
  \lambda^c_{n_q+n-3} \\
  \lambda^c_{n_q+n-2}
\end{bmatrix}.
\]

- On page 320, equation (7.172) should be

\[
\hat{\theta}_{qD}(t) = [1, \hat{\theta}_{n+n_q-1}, \hat{\theta}_{n+n_q-2}, \ldots, \hat{\theta}_1, \hat{\theta}_0]^T \in \mathbb{R}^{n+n_q+1},
\]
equation (7.173) should be

\[
\hat{\theta}_c(t) = [0, \hat{\theta}_{n-1}, \hat{\theta}_{n-2}, \ldots, \hat{\theta}_1, \hat{\theta}_0]^T \in \mathbb{R}^{n+1},
\]
equation (7.174) should be

\[
\hat{\theta}_e(t) = [1, \hat{\theta}_{n-2}, \ldots, \hat{\theta}_1, \hat{\theta}_0]^T \in \mathbb{R}^n,
\]
and equation (7.175) should be

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

- On page 330, in (7.227), “k_1(t) = \frac{-\hat{a}_p(t)-a_m}{b_p(t)}” should be “k_1(t) = \frac{-\hat{a}_p(t)+a_m}{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 \beta” should be “where \hat{\beta}_1 is the estimate of \beta_1”.

- On page 368, in (8.120), “−γ_0” should be “γ_0”.

- On page 369, in (8.125), “\hat{\Phi}_3(t)” should be “\hat{\Phi}_3”, and “c_{533}x_4^3” should “c_{533}x_4^3”.

- On page 376, above (9.31), “\Phi^T_{2i}(t)” should be “\Phi_{2i}(t)”, and “\Phi^T_{2}(t)” should be “\Phi_{2}(t)”.

- On page 376 and page 377, in (9.31), “\Phi^T_{2i}(t)” should be “\Phi_{2i}(t)”, i = 1, 2, \ldots, M.

- On page 378, line 3, “y(t)” should be “x(t)”.

- On page 379, before the second paragraph, add

So far, motivated from adaptive control, we have derived the dynamic equation (9.39) which is to be used for the design of an adaptive estimator (identifier) of a plant

\[
\dot{x} + Ax(t) + Bu(t)
\]
whose parameters A and B are to be estimated (identified). For (9.39), the matrix \(A_m\) now can be chosen independent of the matching condition (9.3): \(A + BK_1^T = A_m\), and its state vector \(x_m(t)\) is generated based on the measured plant state \(x(t)\) and chosen input \(u(t)\). Note that from now on \(r(t), K_1(t)\) and \(K_2(t)\) all become irrelevant anymore. Next we will use \(x_m(t)\) from (9.39) to construct an adaptive parameter estimation (system identification) scheme to generate the desired estimates \(\hat{A}(t)\) and \(\hat{B}(t)\) of the unknown system matrices A and B. In this case, (9.39) may be called an estimator or identifier state equation.
• 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 383, three lines above (9.58), “Z_r(D)” should be “Z_L(D)”.

• On page 390, in the proof of Lemma 9.3, we should start (9.85) with

$$\Theta_1^T \bar{A}(D) = \Lambda(D)I_M - Q_l(D)Z_l(D)$$

for some $\bar{A}(D) = [I_M, DlM, \ldots, D^{v_0 - 1}I_M]^T$. With this change, the new version of (9.86) is

$$I_M - \Theta_1^T \bar{F}(D) - \Theta_2^T F(D)G_0(D) = \Theta_3^* W_m^{-1}(D)G_0(D)$$

for $\bar{F}(D) = \frac{\bar{A}(D)}{\Lambda(D)}$. It then follows that

$$\lim_{D \to \infty} \Theta_1^T \bar{F}(D) = 0$$

as $\lim_{D \to \infty} \Theta_2^T F(D)G_0(D) = 0$ and $\lim_{D \to \infty} \Theta_3^* W_m^{-1}(D)G_0(D) = I_M$, so that $v_0 - 1 < v$, that is, $v_0 = v$ is the choice, making $\bar{A}(D) = A(D)$.

In fact, from (9.83), we have

$$\Lambda(D) K_p^{-1} \xi_m(D) P_l^{-1}(D) = Q_l(D) + R_l(D)P_l^{-1}(D)$$

$$\Lambda(D) K_p^{-1} \xi_m(D) P_l^{-1}(D) Z_l(D) = Q_l(D)Z_l(D) + R_l(D)P_l^{-1}(D) Z_l(D)$$

$$K_p^{-1} \xi_m(D) P_l^{-1}(D) Z_l(D) = \Lambda^{-1}(D)Q_l(D)Z_l(D) + \Lambda^{-1}(D)R_l(D)P_l^{-1}(D) Z_l(D)$$

so that

$$\Theta_1^T \bar{F}(D) = I_M - \Lambda^{-1}(D)Q_l(D)Z_l(D)$$

$$= I_M - K_p^{-1} \xi_m(D) P_l^{-1}(D) Z_l(D) + \Lambda^{-1}(D)R_l(D)P_l^{-1}(D) Z_l(D),$$

implying that $\lim_{D \to \infty} \Theta_1^T \bar{F}(D) = 0$.

• 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), “$\beta(\xi T \zeta + \xi T \xi)$” should be “$\epsilon \beta(\xi T \zeta + \xi T \xi)$”.

• On page 410, in (9.174D), “$\beta(\xi T \zeta + \xi T \xi)$” should be “$\epsilon \beta(\xi T \zeta + \xi T \xi)$”, and the second “$\frac{1}{D^2 + a_0}$” should be “$\frac{f(D)}{D^2 + a_0}$”. Above (9.174D), change “From (9.129)” to “From (9.129) with $h(D) = \frac{1}{f(D)}$”.

• On page 411, line 4 below (9.184D), change “such that $\bar{y}(t)$ or $\hat{y}(t)$ is bounded” to “such that $\bar{y}(t)$ is bounded”.

• On page 412, line 2, change “such that $\bar{y}(t)$ or $\hat{y}(t)$ is bounded” to “such that $\hat{y}(t)$ is bounded”.

• On page 443, under (9.357), “$U$” should be “$U_z$”.

• On page 448, in (9.389), “$\Phi = U \Theta_i$” 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

\[ \ddot{e}(t) = SD_{ij}(D) \left[ [\Phi_{1}^{T} \gamma_{1}, \Phi_{2}^{T} \gamma_{2}, \ldots, \Phi_{M}^{T} \gamma_{M}]^{T} \right] (t). \]

• On page 455, under (9.433), “i = 2, 3, \ldots, M” should be “i = 1, 2, \ldots, M.”

• On page 463, in the second line after (9.486), “mB = (S_{m}B_{m})^{T} > 0” should be “S_{m}B_{m} = (S_{m}B_{m})^{T} > 0.”

• One page 479, 4 lines below (9.594), “\bar{H}” should be “H.”

• One page 483, (9.606) should be

\[ u(t) = Y(q, q_{d}, \dot{q}, \dot{q}_{d}, \dot{q}_{d}, t)\theta^{*}(t) + \frac{1}{2} \frac{\partial D(q, t)}{\partial t}(\dot{q} + v) - K_{D}s. \]

Note that this control law leads the time derivative of \( V(s, \dot{\theta}, t) = \frac{1}{2} s^{T} D(q, t) s \) 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 490, in (9.637), “u_{d}” should be “u”, and in (9.640), “A(D)Z(D)” should be “Z(D)”.

• On page 493, the last line, “\( \Theta^{*}\)” should be “\( \Theta_{3}^{*}\)”.

• On page 494, below (9.655), “\( \varepsilon(t) = \theta^{T}(t)\zeta(t) \)” should be “\( \varepsilon(t) = \bar{\theta}^{T}(t)\zeta(t) \)”; also in (9.656), “\( \zeta \)” should be “\( \zeta \).

To see (9.655), we derive

\[ \bar{\theta}^{T}(t)f(D)[\zeta(t)] = \bar{\theta}^{T}(t)\omega(t) + \Theta_{3}(t)(\xi_{m}(D)[y](t) - r(t)) = \Theta_{3}(t)\xi_{m}(D)[y - y_{m}](t) \]

here the identity \( \bar{\theta}^{T}(t)\omega(t) = \Theta_{3}^{*}\xi_{m}(D)[y - y_{m}](t) \) has been used.

• On page 494, above (9.657), “(9.468)” should be “(9.366)”.

• On page 495, in and below (9.661), “\( \Phi(t) \)” should be “\( \Phi(t - 1) \)”.

• On pages 499-500, Problem 9.34, for part (iii), replace the adaptive law by: \( \bar{\theta}^{T}(t + 1) = \bar{\theta}^{T}(t) - \frac{\Gamma\varepsilon(t)\zeta_{1}^{T}(t)}{1 + \zeta_{1}^{T}(t)\zeta(t)} \), for part (iv), replace the adaptive law by: \( \bar{\theta}^{T}(t + 1) = \bar{\theta}^{T}(t) - \frac{\varepsilon(t)\zeta_{1}^{T}(t)}{1 + \zeta_{1}^{T}(t)\zeta(t)} \), note that the condition on \( \Gamma \) is: \( \Gamma K_{p} + K_{p}^{T}\Gamma - K_{p}^{T}\Gamma K_{p} > 0 \), as

\[ \text{tr}([\bar{\theta}(t + 1)\Gamma\bar{\theta}^{T}(t + 1)] - [\bar{\theta}(t)\Gamma\bar{\theta}^{T}(t)]) = \frac{1}{1 + \zeta_{1}^{T}(t)\zeta(t)} \varepsilon^{T}(t) \left( -\Gamma^{-1} - (\Gamma^{-1})^{T} + \frac{\zeta_{1}^{T}(t)\zeta(t)}{1 + \zeta_{1}^{T}(t)\zeta(t)} \Gamma \right) \varepsilon(t); \]

for part (v), replaced it by: “(v) Repeat parts (i) and (ii) with a normalized adaptive law, for example, \( \bar{\theta}^{T}(t) = -\frac{\Gamma\varepsilon(t)\zeta_{1}^{T}(t)}{1 + \zeta_{1}^{T}(t)\zeta(t)} \), and parts (iii) and (iv) with an unnormalized adaptive law, for example, \( \bar{\theta}^{T}(t + 1) = \bar{\theta}^{T}(t) - \Gamma\varepsilon(t)\zeta_{1}^{T}(t) \), and comment on the results.”
• On page 556, after (10.109), “\(u_d(t) = [u_{d1}(t), \ldots, u_{dm}(t)]^T\)” and “\(\hat{NI}(\cdot) = [\hat{NI}_1(\cdot), \ldots, \hat{NI}_m(\cdot)]^T\)” should be “\(u_d(t) = [u_{d1}(t), \ldots, u_{dM}(t)]^T\)” and “\(\hat{NI}(\cdot) = [\hat{NI}_1(\cdot), \ldots, \hat{NI}_M(\cdot)]^T\)”.

• 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), “\(\phi_4^+\)” should be “\(\phi_4^-\) = \(-\phi_1^+ \otimes \theta^+ \bigtriangleup -[\phi_1^+ \theta^+ T, \phi_2^+ \theta^+ T, \ldots, \phi_{n-1}^+ \theta^+ T]^T \in R^{(n-1)\eta_0}\)”.

• 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 “\(\Phi_3\)” should be “\(\Phi_3\)”.

• On page 538, below (10.192), delete “where \(r_i\) is such that \(L_{g_i}L_j^r_i h_i(x) \neq 0, 1 \leq j \leq M\)”.

• On page 556, (10.288) should be

\[
\omega_{m2}(t) = \frac{(s^{m+1} + k_1 s^m) L_4}{s^n + k_1 s^{n-1} + \ldots + k_{n-1} s + k_n} [\sigma(y) \omega](t) \quad (n - m = \rho \geq 2).
\]

(Note that for the case of \(n - m = 1\), \(\omega_{m2}(t) = \frac{-(k_2 s^{n-2} + k_3 s^{n-3} + \ldots + k_{n-1} s + k_n) L_4}{s^n + k_1 s^{n-1} + \ldots + k_{n-1} s + k_n} [\sigma(y) \omega](t)\), and no derivative of \(\omega_2(t), i = 0, 1, \ldots, m, \) is needed in the backstepping design procedure.)

• On page 569, at the end, add “Since \(r_i > 0\) and \(s_{ki} > 0\) in (10.328) are design parameters, they can be chosen to be larger to make the effect of \(\frac{d^2}{4r_i} + \sum_{i=2}^\rho \frac{d^2}{4r_i} \) and \(\sum_{k=2}^{\rho-1} \sum_{i=1}^{g_k} \frac{\chi_i^2}{4a_{ki}}\) on \(V_\rho\) smaller, to reduce the tracking error \(z_1(t) = y(t) - y_m(t)\)."