

# Supplementary material concerning the paper “Estimation and Prevention of Sensor Replacement Attacks in Supervisory Control Systems”

## I. PROOF OF THEOREM 1

*Theorem 1:* Given a plant  $G$  and a supervisor  $S$ , (1)  $S/G$  is strongly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$  iff there exists a state  $b_o$  in  $E_{S/G}$  such that  $Fir(b_o) \subseteq X_u$ ; (2)  $S/G$  is weakly SR-estimable w.r.t.  $P_o$ ,  $\Sigma_a$ , and  $X_u$  iff there exists a state  $b_o$  in  $E_{S/G}$  such that  $Fir(b_o) \cap X_u \neq \emptyset$ , and for all states  $b'_o$  in  $E_{S/G}$ ,  $Fir(b'_o) \cap (X \setminus X_u) \neq \emptyset$ .

*Proof:* (1) ( $\Leftarrow$ ) Suppose that there exists a state  $b_o$  in  $E_{S/G}$  such that  $Fir(b_o) \subseteq X_u$ . For all states  $(x, q)$  in  $b_o$ , we have  $x \in X_u$ . According to the construction of  $E_{S/G}$ , for any decision string  $\phi \in \Sigma_o \times (\Sigma_o \cup \{\varepsilon\})$  such that  $f_e(b_{0,o}, \phi) = b_o$ , we have that for all decision strings  $\omega' \in P_o^{a-1}(\phi) \cap L(M_a)$ ,  $f(x_0, \alpha(\omega')) \in X_u$ . Then, there exists  $\omega \in L(M_a)$  with  $P_o^a(\omega) = P_o^a(\omega') = \phi$  such that the condition in Definition 1 holds, i.e.,  $S/G$  is strongly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$ .

( $\Rightarrow$ ) Suppose that  $S/G$  is strongly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$ . Then, there exists a decision string  $\omega \in L(M_a)$  such that the condition in Definition 1 hold. Let  $\phi = P_o^a(\omega)$ . By Definition 3, it holds  $\phi \in L(E_{S/G})$ , i.e., there exists a state  $b_o$  such that  $f_e(b_{0,o}, \phi) = b_o$ . For any state  $(x, q)$  in  $b_o$ , there exists a decision string  $\omega' \in P_o^{a-1}(\phi) \cap L(M_a)$  such that  $f_a((x_0, q_0), \omega') = (x, q)$  and  $x \in X_u$ , i.e.,  $Fir(b_o) \subseteq X_u$ .

(2) ( $\Leftarrow$ ) Suppose that there exists a state  $b_o$  in  $E_{S/G}$  such that  $Fir(b_o) \cap X_u \neq \emptyset$ . Then, there exists a state  $(x, q)$  in  $b_o$  such that  $x \in X_u$ . According to the construction of  $E_{S/G}$ , given a decision string  $\phi \in \Sigma_o \times (\Sigma_o \cup \{\varepsilon\})$  such that  $f_e(b_{0,o}, \phi) = b_o$ , there exists a decision string  $\omega \in P_o^{a-1}(\phi) \cap L(M_a)$  such that  $f(x_0, \alpha(\omega)) \in X_u$ , i.e., condition (1) in Definition 2 hold. Suppose that for all states  $b'_o$  in  $E_{S/G}$ ,  $Fir(b'_o) \cap (X \setminus X_u) \neq \emptyset$ , i.e., there exists a state  $(x', q')$  in  $b'_o$  such that  $x' \notin X_u$ . According to case (1),  $S/G$  is not strongly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$ . By Definition 2, we conclude that  $S/G$  is weakly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$ .

( $\Rightarrow$ ) Suppose that  $S/G$  is weakly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$ . Then, there exists a decision string  $\omega \in L(M_a)$  such that  $f(x_0, \alpha(\omega)) \in X_u$ , and  $S/G$  is not strongly SR-estimable w.r.t.  $P_o^a$ ,  $\Sigma_a$ , and  $X_u$ . Due to  $P_o^a(\omega) \in L(E_{S/G})$ , there exists a state  $(b_o, d_o)$  such that  $f_e(b_{0,o}, P_o^a(\omega)) = b_o$ . By  $f(x_0, \alpha(\omega)) \in X_u$ , there exists a state  $(x, q)$  in  $b_o$  such that  $x \in X_u$  (i.e.,  $Fir(b_o) \cap X_u \neq \emptyset$ ). By case (1), for any state

$b'_o$  in  $E_{S/G}$ , there exists  $(x', q')$  in  $b'_o$  such that  $x' \notin X_u$ , i.e.,  $Fir(b'_o) \cap (X \setminus X_u) \neq \emptyset$ . This completes the proof. ■

## II. PROOF OF THEOREM 2

*Theorem 2:* Given  $E_{S/G}$  w.r.t.  $S/G$ , (1) let  $L_{sb} \neq \emptyset$  and  $BS = BS_s$ . An SSR-safe DI-function  $D$  exists if and only if the DIS  $\Upsilon^{BS}$  w.r.t.  $E_{S/G}$  and  $BS$  is not an empty automaton; (2) let  $L_{sb} \cup L_{wb} \neq \emptyset$  and  $BS = BS_s \cup BS_w$ . An SR-safe DI-function  $D$  exists if and only if the DIS  $\Upsilon^{BS}$  w.r.t.  $E_{S/G}$  and  $BS$  is not an empty automaton.

*Proof:* (1) ( $\Leftarrow$ ) If the DIS  $\Upsilon^{BS}$  is not the empty automaton, there exists an SSR-safe DI-function  $D$  that can be synthesized from  $\Upsilon^{BS}$  according to Proposition 1.

( $\Rightarrow$ ) If an SSR-safe DI-function  $D$  exists, it holds that  $D$  can be synthesized from the DIS based on Proposition 1. Then, the DIS is not an empty automaton. Thus, this theorem holds.

(2) It can be proved in the same way as (1). ■

## III. CONSTRUCTION OF A DIS

We briefly review the construction of an “All insertion structure” in [19]. Let  $\mathcal{D} = (M_1, \Sigma, \delta_1, m_{0,1})$  and  $\mathcal{A} = (M_2, \Sigma, \delta_2, m_{0,2})$  be two automata.

In [19], the set of all information states is denoted by  $\mathcal{Q} = M_1 \times M_2$ , and the AIS is the tuple:

$$\text{AIS} = (Y, Z, \Sigma, M_1, f_{\text{AIS},yz}, f_{\text{AIS},zy}, y_0)$$

where  $\Sigma$  is the set of events in  $\mathcal{A}$ .  $M_1$  is the set of states in  $\mathcal{D}$ .  $Y \subseteq \mathcal{Q}$  is the set of  $Y$ -states.  $Z \subseteq \mathcal{Q} \times \Sigma$  is the set of  $Z$ -states. Let  $\mathcal{Q}(z)$ ,  $\mathcal{E}(z)$  denote the information state component and event component of  $z \in Z$  respectively, so that  $z = (\mathcal{Q}(z), \mathcal{E}(z))$ .  $f_{\text{AIS},yz} : Y \times \Sigma \rightarrow Z$  is the transition function from  $Y$ -state to  $Z$ -state. For  $y = (m_1, m_2) \in Y$ ,  $\sigma \in \Sigma$ , we have:  $f_{\text{AIS},yz}(y, \sigma) = z \Rightarrow [\delta_2(m_2, \sigma)!] \wedge [\mathcal{Q}(z) = y] \wedge [\mathcal{E}(z) = \sigma]$ .  $f_{\text{AIS},zy} : Z \times M_1 \rightarrow Y$  is the transition function from  $Z$ -state to  $Y$ -state. For  $z = ((m_1, m_2), \sigma) \in Z$ ,  $m'_1 \in M_1$ , we have:  $f_{\text{AIS},zy}(z, m'_1) = y \Rightarrow [\exists s \in \Sigma^* \text{ s.t. } \delta_1(m_1, s) = m'_1] \wedge [\delta_1(m'_1, \sigma)!] \wedge [y = (\delta_1(m'_1, \sigma), \delta_2(m_2, \sigma))]$ .  $y_0 \in Y$  is the unique initial  $Y$ -state, where  $y_0 = (m_{0,1}, m_{0,2})$ .

Given two automata  $\mathcal{D} = (M_1, \Sigma, \delta_1, m_{0,1})$  and  $\mathcal{A} = (M_2, \Sigma, \delta_2, m_{0,2})$ , the construction procedure for the AIS consist of two steps: (1) obtaining the  $\text{AIS}_{pre}$ , and (2) obtaining

the AIS. Based on  $\mathcal{D}$  and  $\mathcal{A}$ , the game-like structure  $\text{AIS}_{pre}$  can be obtained by Algorithm 1 in [19]. By Algorithm 2 in [19], the AIS can be obtained by pruning away all the inappropriate insertion choices in the  $\text{AIS}_{pre}$ .

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**Algorithm 1:** Construction  $\text{AIS}_{pre}$  in [19]

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**Input:**  $\mathcal{D} = (M_1, \Sigma, \delta_1, m_{0,1})$  and  $\mathcal{A} = (M_2, \Sigma, \delta_2, m_{0,2})$   
**Output:**  $\text{AIS}_{pre} = (Y, Z, \Sigma, M_1, f_{\text{AIS}_{pre}, yz}, f_{\text{AIS}_{pre}, zy}, y_0)$

- 1  $y_0 := (m_{0,1}, m_{0,2})$ ,  $Y := \{y_0\}$ ,  $Z := \emptyset$ ;
- 2 **for all**  $y = (m_1, m_2) \in Y$  **that have not been examined do**
- 3   **for**  $\sigma \in \Sigma$  **do**
- 4     **if**  $\delta_2(m_2, \sigma)$  **is defined then**
- 5        $f_{\text{AIS}_{pre}, yz}(y, \sigma) := (y, \sigma)$ ;
- 6        $Z := Z \cup \{f_{\text{AIS}_{pre}, yz}(y, \sigma)\}$ ;
- 7 **for all**  $z = (y, \sigma) = ((m_1, m_2), \sigma) \in Z$  **that have not been examined do**
- 8   **for**  $m' \in M_1$  **do**
- 9     **if**  $\delta_1(m', \sigma)$  **is defined and**  $\exists t \in \Sigma^*$  **such that**  
 $m' = \delta_1(m', t)$  **then**
- 10        $f_{\text{AIS}_{pre}, zy}(z, m') := (\delta_1(m', \sigma), \delta_2(m_2, \sigma))$ ;
- 11        $Y := Y \cup \{f_{\text{AIS}_{pre}, zy}(z, m')\}$ ;
- 12 **Go back to step 2; repeat until all accessible part has been built;**

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**Algorithm 2:** Construct AIS in [19]

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**Input:**  $\text{AIS}_{pre} = (Y, Z, \Sigma, M_1, f_{\text{AIS}_{pre}, yz}, f_{\text{AIS}_{pre}, zy}, y_0)$   
**Output:** AIS =  $(Y, Z, \Sigma, M_1, f_{\text{AIS}, yz}, f_{\text{AIS}, zy}, y_0)$

- 1 Obtain an automaton as  
 $A = (Y \cup Z, \Sigma \cup M_1, f_{\text{AIS}_{pre}, yz} \cup f_{\text{AIS}_{pre}, zy}, y_0)$ ;
- 2 Mark all the Y-states in A;
- 3 Let  $\Sigma$  be uncontrollable and  $M_1$  be controllable;
- 4 Trim A and let  $A_{trim}$  be the specification automaton;
- 5 Obtain the AIS as the automaton obtained from  
 $[L_m(A_{trim})]^{\uparrow C}$  w.r.t.  $L(A)$  by following the standard  
 $\uparrow C$  algorithm in [20];
- 6 **return** the AIS as  
AIS =  $(Y, Z, \Sigma, M_1, f_{\text{AIS}, yz}, f_{\text{AIS}, zy}, y_0)$ ;

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Next, we integrate these two algorithms and transform them into one algorithm (Algorithm 3 in the supplementary material) to build a DIS in our work. Given an attacker estimator  $E_{S/G}$  and a bad state set  $BS \in \{BS_s, BS_s \cup BS_w\}$ , we first obtain a safe estimator  $E_{S/G}^{BS}$  w.r.t.  $S/G$  and  $BS$  by removing all the states in  $BS$  from  $E_{S/G}$  and keeping the accessible part in step 1. Step 2 initializes the sets  $I_y$  and  $I_z$ . Steps 3–7 and 8–12 define the transitions from Y-states to Z-states and the transitions from Z-states to Y-states, respectively. In step 13, an automaton  $\Upsilon = (I_y \cup I_z, \Xi_o \cup B_o^{BS}, f_{pre, yz}, f_{pre, zy}, y_0)$  is built. We prune away all inadmissible insertion cases that lead to deadlock at Z-states in  $\Upsilon$  by steps 14–17. In step 18, a DIS is constructed. Given an estimator with  $|B_o|$  states and

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**Algorithm 3:** Construction of DIS

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**Input:** An attacker estimator  $E_{S/G} = (B_o, \Xi_o, f_e, b_{0,o})$   
and a bad state set  $BS \in \{BS_s, BS_s \cup BS_w\}$   
**Output:** A DIS  $\Upsilon^{BS} = (I_y, I_z, \Xi_o, B_o^{BS}, f_{yz}, f_{zy}, y_0)$

- 1 Construct a safe estimator  
 $E_{S/G}^{BS} = (B_o^{BS}, \Xi_o, f_e^{BS}, b_{0,o})$  by removing all the  
sets in  $BS$  from  $E_{S/G}$  and keeping the accessible  
part;
- 2  $I_y := \{y_0\} = \{(b_{0,o}, b_{0,o})\}$ ,  $I_z := \emptyset$ ;
- 3 **for all**  $i_y = (b_{o1}, b_{o2}) \in I_y$  **that have not been examined do**
- 4   **for**  $\sigma_{\sigma'} \in \Xi_o$  **do**
- 5     **if**  $f_e(b_{o2}, \sigma_{\sigma'})!$  **then**
- 6        $f_{pre, yz}(i_y, \sigma_{\sigma'}) := (i_y, \sigma_{\sigma'})$ ;
- 7        $I_z := I_z \cup \{f_{pre, yz}(i_y, \sigma_{\sigma'})\}$ ;
- 8 **for all**  $i_z = (i_y, \sigma_{\sigma'}) = ((b_{o1}, b_{o2}), \sigma_{\sigma'}) \in I_z$  **that have not been examined do**
- 9   **for**  $b'_{o1} \in B_o^{BS}$  **do**
- 10     **if**  $f_e^{BS}(b'_{o1}, \sigma_{\sigma'})!$  **and there exists**  $\omega \in \Xi_o^*$  **such**  
**that**  $b'_{o1} = f_e^{BS}(b_{o1}, \omega)$  **then**
- 11        $f_{pre, zy}(i_z, b'_{o1}) :=$   
 $(f_e^{BS}(b'_{o1}, \sigma_{\sigma'}), f_e(b_{o2}, \sigma_{\sigma'}))$ ;
- 12        $I_y := I_y \cup \{f_{pre, zy}(i_z, b'_{o1})\}$ ;
- 13 **Go back to step 2, repeat until all accessible part has been built, and build an automaton as**  
 $\Upsilon = (I_y \cup I_z, \Xi_o \cup B_o^{BS}, f_{pre, yz}, f_{pre, zy}, y_0)$ ;
- 14 Mark all the Y-states in  $\Upsilon$ ;
- 15 Let  $\Xi_o$  be uncontrollable and  $B_o^{BS}$  be controllable;
- 16 Trim  $\Upsilon$  and let  $\Upsilon_{trim}$  be the specification automaton;
- 17 Construct DIS  $\Upsilon^{BS}$  as the automaton obtained from  
 $[L_m(\Upsilon_{trim})]^{\uparrow C}$  w.r.t.  $L(\Upsilon)$  by using the standard  
 $\uparrow C$  algorithm in [20];
- 18 **return** DIS as  $\Upsilon^{BS} = (I_y, I_z, \Xi_o, B_o^{BS}, f_{yz}, f_{zy}, y_0)$ ;

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the set of observable decision events  $\Xi_o = \Sigma_o \times (\Sigma_o \cup \{\varepsilon\})$ , the obtained DIS has at most  $(|\Xi_o| + 1)|B_o|^2$  states, and the computational complexity for constructing the DIS is  $\mathcal{O}(|B_o|^6)$  by referring to [18], [19].

Algorithm 3 is an integrated version of Algorithms 1 and 2 in [19]. Intuitively, we first take the automata  $E_{S/G}^{BS}$  and  $E_{S/G}$  as the input of Algorithm 1, i.e., substituting the automata  $E_{S/G}^{BS}$  and  $E_{S/G}$  for the automata  $\mathcal{D}$  and  $\mathcal{A}$ , respectively. Then, we go directly to the step 1 of Algorithm 2 to obtain an automaton  $\Upsilon = (I_y \cup I_z, \Xi_o \cup B_o^{BS}, f_{pre, yz}, f_{pre, zy}, y_0)$ . Finally, we build a DIS  $\Upsilon^{BS}$  by pruning away all inadmissible insertion cases that lead to deadlock at Z-states in  $\Upsilon$ .

#### IV. FIGURE OF EXAMPLE 5

We build an automaton  $\Upsilon$  based on  $E_{S/G}$  and  $BS = BS_s$  as shown in Fig. 1 of this supplementary material. All dashed states and arcs should be pruned since they correspond to inadmissible insertion cases, and a DIS  $\Upsilon^{BS}$  is obtained. We use  $\sigma_{\sigma'}$  and  $\sigma_{1\sigma'_1}$  to represent any event in decision event sets  $\{b_b, b_\varepsilon, b_d\}$  and  $\{b_b, b_\varepsilon, b_d, d_d, d_\varepsilon, d_b\}$ , respectively. For

instance, we use a transition  $f_{yz}(\chi_6\chi_6, \sigma_{\sigma'}) = (\chi_6\chi_6, \sigma_{\sigma'})$  to briefly represent the transitions  $f_{yz}(\chi_6\chi_6, b_b) = (\chi_6\chi_6, b_b)$ ,  $f_{yz}(\chi_6\chi_6, b_e) = (\chi_6\chi_6, b_e)$ , and  $f_{yz}(\chi_6\chi_6, b_d) = (\chi_6\chi_6, b_d)$ .

## V. FIGURE OF EXAMPLE 6

In Fig. 2 of this supplementary material, an automaton  $\Upsilon$  is constructed based on  $E_{S/G}$  and  $BS = BS_s \cup BS_w$ , and a DIS  $\Upsilon^{BS}$  is obtained by removing all the dashed states and arcs in  $\Upsilon$ .

## REFERENCES

- [1] P. J. Ramadge and W. M. Wonham, "Supervisory control of a class of discrete event processes," *SIAM J. Control Optim.*, vol. 25, no. 1, pp. 206–230, Jan. 1987.
- [2] C. N. Hadjicostis, S. Lafortune, F. Lin, and R. Su, "Cybersecurity and supervisory control: A tutorial on robust state estimation, attack synthesis, and resilient control," in *Proc. 61st IEEE Conf. Decis. Control (CDC)*, Cancun, Mexico, Dec. 2022, pp. 3020–3040.
- [3] Q. Zhang, C. Seatzu, Z. Li, and A. Giua, "Selection of a stealthy and harmful attack function in discrete event systems," *Sci. Rep.*, vol. 12, no. 1, p. 16302, Sep. 2022.
- [4] Y. Li, C. N. Hadjicostis, N. Wu, and Z. Li, "Error- and tamper-tolerant state estimation for discrete event systems under cost constraints," *IEEE Trans. Autom. Control*, pp. 1–8, Feb. 2023, doi: 10.1109/TAC.2023.3239590.
- [5] R. Meira-Gôes, E. Kang, R. H. Kwong, and S. Lafortune, "Stealthy deception attacks for cyber-physical systems," in *Proc. 56th IEEE Conf. Decis. Control (CDC)*, Melbourne, Australia, Dec. 2017, pp. 4224–4230.
- [6] —, "Synthesis of sensor deception attacks at the supervisory layer of cyber-physical systems," *Automatica*, vol. 121, p. 109172, Nov. 2020.
- [7] M. Wakaiki, P. Tabuada, and J. P. Hespanha, "Supervisory control of discrete-event systems under attacks," *Dyn. Games Appl.*, vol. 9, no. 4, pp. 965–983, Dec. 2019.
- [8] R. Meira-Gôes, S. Lafortune, and H. Marchand, "Synthesis of supervisors robust against sensor deception attacks," *IEEE Trans. Autom. Control*, vol. 66, no. 10, pp. 4990–4997, Jan. 2021.
- [9] L. K. Carvalho, Y.-C. Wu, R. Kwong, and S. Lafortune, "Detection and mitigation of classes of attacks in supervisory control systems," *Automatica*, vol. 97, pp. 121–133, Nov. 2018.
- [10] R. Su, "Supervisor synthesis to thwart cyber attack with bounded sensor reading alterations," *Automatica*, vol. 94, pp. 35–44, Aug. 2018.
- [11] R. Meira-Gôes, H. Marchand, and S. Lafortune, "Dealing with sensor and actuator deception attacks in supervisory control," *Automatica*, vol. 147, p. 110736, Nov. 2023.
- [12] Y. Zhu, L. Lin, and R. Su, "Supervisor obfuscation against actuator enablement attack," in *Proc. 18th European Control Conference (ECC)*, Napoli, Italy, Jun. 2019, pp. 1760–1765.
- [13] L. Lin and R. Su, "Synthesis of covert actuator and sensor attackers," *Automatica*, vol. 130, p. 109714, Aug. 2021.
- [14] D. You, S. Wang, M. Zhou, and C. Seatzu, "Supervisory control of petri nets in the presence of replacement attacks," *IEEE Trans. Autom. Control*, vol. 67, no. 3, pp. 1466–1473, Mar. 2021.
- [15] T. Yadav and A. M. Rao, "Technical aspects of cyber kill chain," in *Proc. Int. Symp. Secur. Comput. Commun.* Springer, 2015, pp. 438–452.
- [16] S. Roy, N. Sharmin, J. C. Acosta, C. Kiekintveld, and A. Laszka, "Survey and taxonomy of adversarial reconnaissance techniques," *ACM Comput. Surv.*, vol. 55, no. 6, pp. 1–38, Jun. 2023.
- [17] Y.-C. Wu and S. Lafortune, "Synthesis of insertion functions for enforcement of opacity security properties," *Automatica*, vol. 50, no. 5, pp. 1336–1348, May 2014.
- [18] Y. Ji, Y.-C. Wu, and S. Lafortune, "Enforcement of opacity by public and private insertion functions," *Automatica*, vol. 93, pp. 369–378, Jul. 2018.
- [19] R. Liu and J. Lu, "Enforcement for infinite-step opacity and k-step opacity via insertion mechanism," *Automatica*, vol. 140, p. 110212, Jun. 2022.
- [20] C. G. Cassandras and S. Lafortune, *Introduction to Discrete Event Systems*. Springer Science & Business Media, 2009.
- [21] J. Franco, A. Aris, B. Canberk, and A. S. Uluagac, "A survey of honeypots and honeynets for internet of things, industrial internet of things, and cyber-physical systems," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 4, pp. 2351–2383, Aug. 2021.
- [22] G. K. Edwin, S. V. Edwards, G. J. W. Kathrine, G. M. Palmer, A. Bertia, and S. Vijay, "Honeypot based intrusion detection system for cyber physical system," in *Proc. Int. Conf. Augmented Intell. Sustain. Syst. (ICAISS)*, Trichy, India, Nov. 2022, pp. 958–962.
- [23] X. Li, C. N. Hadjicostis, and Z. Li, "Opacity enforcement in discrete event systems using extended insertion functions under inserted language constraints," *IEEE Trans. Autom. Control*, vol. 68, no. 11, pp. 6797–6803, Nov. 2023.
- [24] R. Liu, J. Lu, Y. Liu, X. Yin, and C. N. Hadjicostis, "Opacity enforcement via greedy privately-and-publicly known insertion functions," *IEEE Trans. Autom. Control*, vol. 69, no. 4, pp. 2500–2506, Apr. 2024.
- [25] Z. He and Z. Li, "Supplementary material concerning the paper 'Estimation and Prevention of Sensor Replacement Attacks in Supervisory Control Systems,'" 2024. [Online]. Available: <https://github.com/ZhaoyangHe-MUST/Supplementary-material/blob/main/generic-color.pdf>

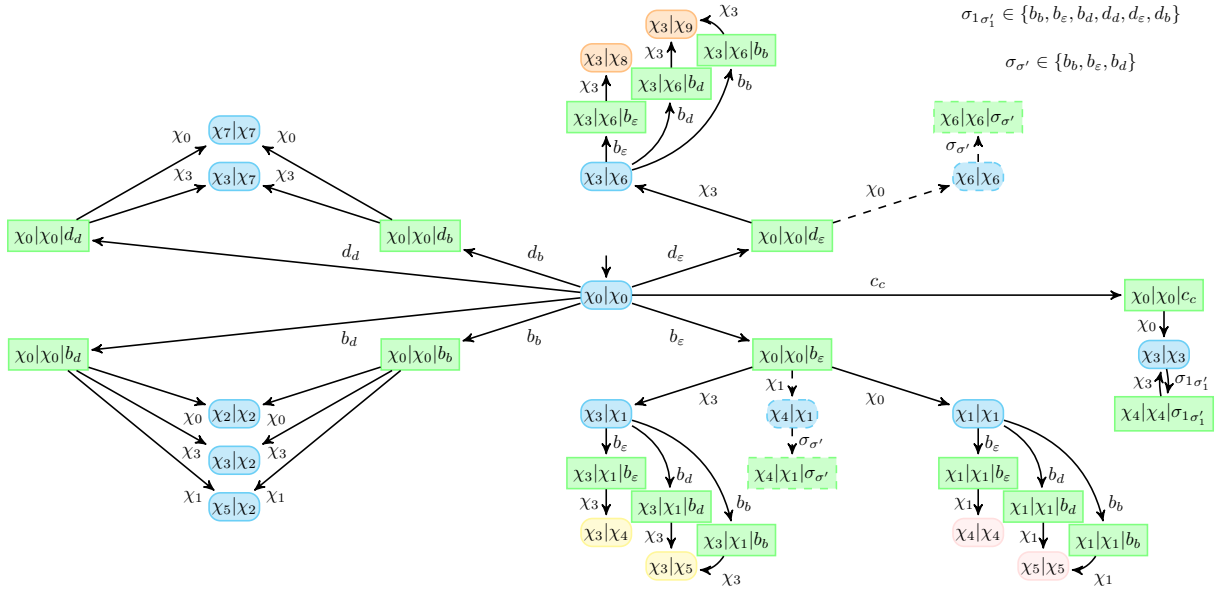


Fig. 1. A DIS w.r.t.  $E_{S/G}$  and  $BS_s$  in Example 5.

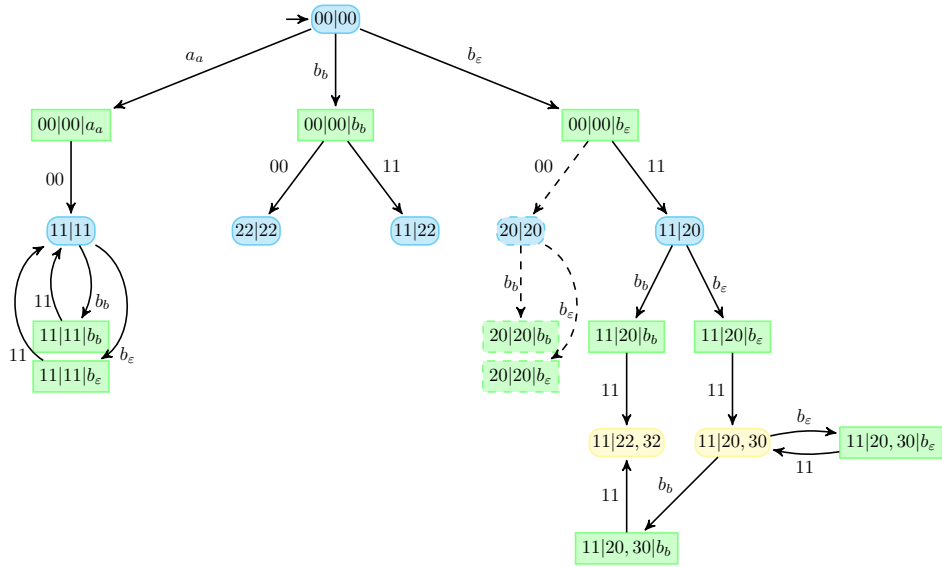


Fig. 2. A DIS w.r.t.  $E_{S/G}$  and  $BS_s \cup BS_w$  in Example 6.