Ruhr University Bochum
Institute of Automation and Computer Control
Prof. Dr.-Ing. J. Lunze

Universitätsstrasse 150 Phone +49-234-32 24071
D-44805 Bochum, Germany Fax +49-234-32 14101

Diagnosis of Timed Discrete-Event Systems

M.Eng. Peerasan Supavatanakul
Supavatanakul@esr.ruhr-uni-bochum.de

1 Diagnosis of discrete–event systems

The task of fault diagnosis is to decide if faults have occurred in the system and to identify them. The aim of this project is to develop fault diagnostic methods for discrete–event systems. The main idea is to test the consistency of the measured event–time sequence generated by the discrete–event system with the timed discrete–event model (Figure 1).

The main motivation for dealing with timed discrete–event representation is that temporal distance between events includes important information for diagnosis. For example, the degradation of the system performance due to a fault changes first the temporal distance between event rather than the event sequence itself [3, 5]. To solve this problem, a suitable representation of the system has to be first determined. Then a diagnostic algorithm based on this representation must be developed.

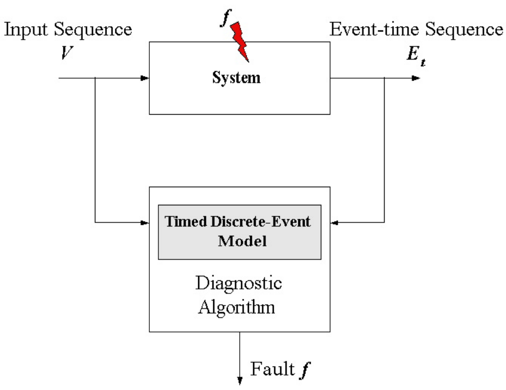

Figure 1: Model-based diagnosis of a timed discrete–event system.

2 Timed discrete–event models

The proposed diagnostic approach is based on *timed automata*. Timed automata are finite state machines with timed transition behaviour. For a timed automaton

$$\mathcal{A}_T(\mathcal{N}_x, \mathcal{N}_v, \mathcal{N}_w, R, z(0)),$$

$\mathcal{N}_z$ represents the set of states, $\mathcal{N}_v$ the set of inputs, $\mathcal{N}_w$ the set of output, R the state transition relation of the timed automaton and $z(0)$ the initial state of the automaton. The timed automaton can be used for explicit representation of the timed discrete-event systems by substituting the set of automaton states $\mathcal{N}_z$ with the set of events $\mathcal{N}_e$. Furthermore to represent the fault effect, the fault set $\mathcal{N}_f$ occurs as a new argument in the automaton. Thus the timed automaton to represent the timed discrete–event systems is

$$\mathcal{A}_T(\mathcal{N}_e, \mathcal{N}_v, \mathcal{N}_f, \mathcal{N}_w, R, e(0)).$$

The state transition relation R of the timed automaton is described by

$$R = (L, T), \tag{1}$$

L is the dynamical behaviour of the timed automaton

$$L \subseteq \mathcal{N}_e \times \mathcal{N}_e \times \mathcal{N}_u \times \mathcal{N}_w \times \mathcal{N}_f \tag{2}$$

which also depends on the set of fault $\mathcal{N}_f$. T is the temporal function of the timed automaton. It represents the mapping

$$T \subseteq \mathbb{R}^+ \times \mathbb{R}^+ \tag{3}$$

and describes the sojourn time for each event e. For an event e, the sojourn time is the time interval $[\tau_{\min}(e), \tau_{\max}(e)]$. Accordingly the movement of the timed automaton can only take place only if (2) and (3) are satisfied.

Figure 2 shows an automaton graph whose nodes represent events and any arc between two nodes represents a possible transition of one event to another. The number above each arc represents the time between events (sojourn time). The transition can take place if the automaton receives some input symbol $v \in \mathcal{N}_v$ and simultaneously produces the output symbol $w \in \mathcal{N}_v$ within the sojourn time. $\boldsymbol{f}$ symbolises the fault symbol in the fault set $\mathcal{N}_f$, whereby $\boldsymbol{f} = 1$ means that a fault has occurred. Figure 2 also shows that the system with fault (in grey) behaves differently from the faultless system (in black).

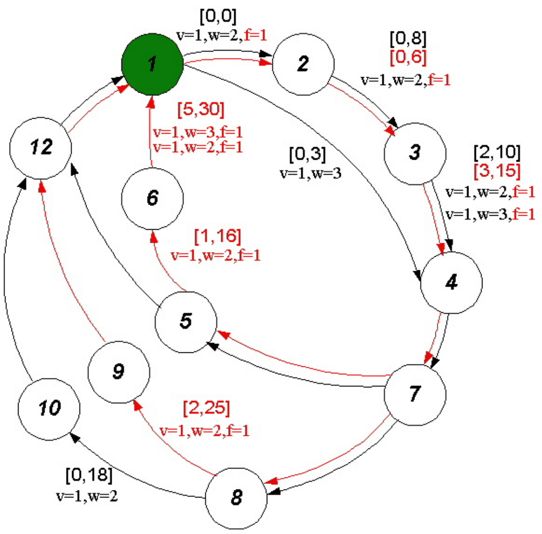

Figure 2: Graph representing a timed automaton.

3 Diagnosis based on timed automata

The diagnostic method applied in this project is *consistency based diagnosis*. The main idea is to compare the observed sequence of events with the behaviour of the model. The diagnostic task is posed as the question whether the system can generate an event–time sequence $\boldsymbol{E}_t$ upon receiving the input sequence $\boldsymbol{V}$ as shown in Figure 1. If some fault $\boldsymbol{f}$ occurs in the system, the diagnostic algorithm should determine the fault from the inconsistency between measured event–time sequence $\boldsymbol{E}_t$ and event–time sequence predicted by the model of the faultless system (fault detection). To identify the fault in the system, the model should include fault information, i.e. the model of faulty system should be available.
The main idea of the model-based diagnosis of the system described by timed automata $\mathcal{A}_T$ is elaborated as follows:

- **Fault detection:** The algorithm should determine if a fault $\boldsymbol{f}$ has occurred in the system. For this, the event–time sequence $\boldsymbol{E}_t$ generated by the system is tested for consistency with the timed automata. If the measurements are inconsistent with the automaton representing the faultless system, it is known that some faults have occurred.

- **Fault identification:** If a fault has occurred, the faulty component in the system has to be determined. In this step, the event–time sequence $\boldsymbol{E}_t$ generated by the system is tested for consistency with timed automata representing the faulty system. If the generated sequence coincides with the timed automata representing some fault $\boldsymbol{f}$, it can be said that the fault $\boldsymbol{f}$ is likely to occur in the system.

Note that the principle of consistency based diagnosis can only exclude faults as candidate solution of the diagnostic problem but it cannot prove that a fault has occur. The fault identification is certain if the fault which can occur in the system is a singleton.

4 Example

As an example, consider the batch process shown in Figure 3. The product of this process results from a chemical reaction between a substance and a solvent in the reactors $R1$ and $R2$. A certain amount of substance is pumped through inlet valves V_1 and V_5 into $R1$ and $R2$, respectively. A certain quantity of solvent is then provided to $R1$ and $R2$ from $B1$ through the valves V_2 and V_6. After the reaction is completed the resulting substance flows to $B2$ through the outlet valves V_4 and V_8. The product is finally separated from the resulting substance in the filter $F1$.
The available measurements are the discrete levels from both reactors measured from the capacitive sensors mounted at both reactors $R1$ and $R2$ shown in Figure 3. Example of faults which should be detected are the blockage of valves V_4 and V_6. This diagnostic problem is solved in the project by the method outlined in Section 3.

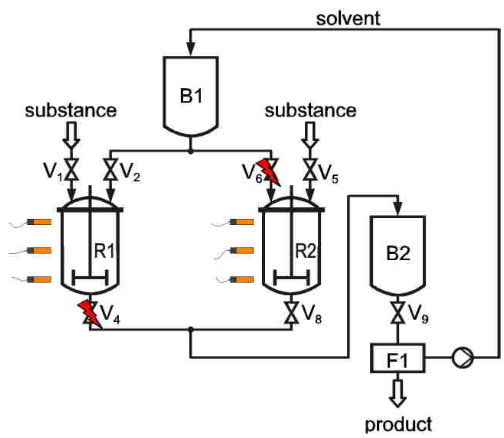

Figure 3: A batch process subjected to some blockages.

Cooperation

This project is supported by Deutsche Forschungsgemeinschaft (LU462/13) and carried out in close cooperation with the Institute of Control Systems of the University Karlsruhe (TH), Karlsruhe, Germany.

References

[1] Lunze, J.: *Künstliche Intelligenz für Ingenieure*, Band 2, Oldenbourg–Verlag, München 1995.

[2] Förstner, D., Lunze, J.: Discrete–event models of quantised systems for diagnosis, *International Journal of Control*,74, 2001.

[3] Lunze, J.: Ein Diagnoseverfahren für kontinuierliche Systeme mit quantisierten Meßgeräten, *Automatisierungstechnik*, 48, 2000.

[4] Lunze, J.; Schröder, J.; Supavatanakul, P.: Diagnosis of discrete–event systems: the method and an example, *Proceedings of the 12th International Workshop on Principles of Diagnosis*, Via Lattea, 2001.

[5] Lunze, J.; Supavatanakul, P.: Diagnosis of discrete–event systems described by timed automata, *15th IFAC World Congress*, Barcelona, 2002.