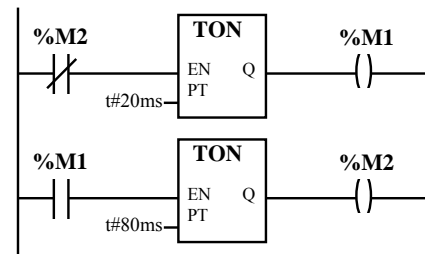


Read all questions of the exam carefully before starting to answer.

- Provide detailed justifications to all answers.
- The use of bibliographic material, either in paper or in digital format is allowed.
- Exchange of information is forbidden (e.g. voice, WiFi, Bluetooth, GPRS, WAP,...).
- Exam duration: 3 hours.

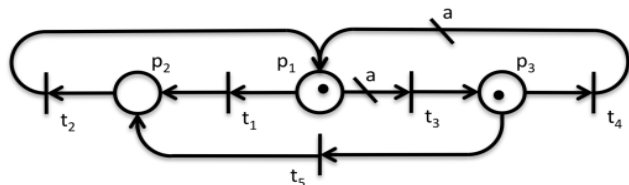
Q1. Logic: Implement in Ladder two latching functions (i) $X = A \text{ OR } (\text{NOT}(B) \text{ AND } X)$, and (ii) $X = (A \text{ OR } X) \text{ AND NOT}(B)$, where **A** and **B** are input signals and **X** is a PLC memory. (iii) Show that the two functions are similar but not exactly equivalent by sketching time responses involving the inputs **A**, **B** and the output **X**.

Q2. Scan cycle: Consider that the ladder diagram in the next figure is the single code run by a PLC, in a MAST section configured to be cyclic. The PLC input and output take **0.1msec+0.1msec** and each ladder instruction (contact read, coil write, timer) takes about **0.05msec**. At $t=0$ the memory cells **%M1** and **%M2** have the logic value False. The timers have preset values of **20msec** and **80msec**. (i) Indicate the scan period of the PLC. (ii) Sketch the time responses of **%M1** and **%M2** indicating clearly the time scale.



Q3. ST Program: (i) Implement a counting program in Structured Text using basic instructions as IF-THEN-ELSE statements, algebraic operations and logic operations. The counting is kept in the word **%MW100** and is limited by the program to be at most **200**. The program counts rising edges of the input **%i0.3.15**. After **3** rising edges in **%i0.3.15**, the memory bit **%M100** is set "True" (logic 1). The activation of the input **%i0.3.14** resets the counting value. (ii) Let **T** denote the scan period in the worst case. Let **T-δ** denote the minimum scan period. Time $\delta \geq 0$ is the time saved because of not running code within some of the THEN or ELSE statements. Indicate in your program the code associated to δ . Give a time estimate for δ assuming that only the assignments, denoted by the symbol ":", consume time. Consider that each assignment takes **0.01ms**.

Q4. PN properties: Consider the Petri net graph shown in the next figure. Note that there are two arcs with generic non-negative weights 'a'.



Let $a=0$.

- Discuss the conservativeness and the boundness of the aforementioned Petri net, resorting to a reachability (sub)tree.
- Discuss the liveness of each transition and the overall level of liveness for the Petri net.

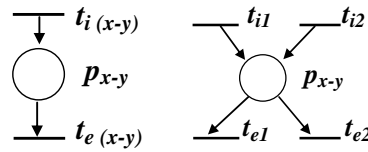
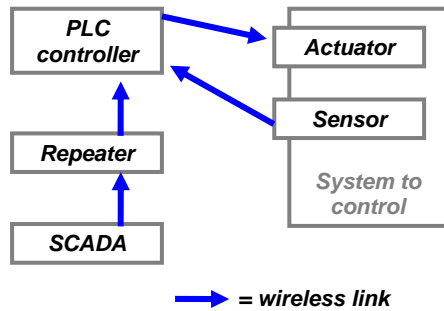
Let $a=1$.

- Discuss the conservativeness of the Petri net, for this case, and provide the weight vector.
- Resorting to the Method of the Matrix Equations, study if and how the marking $\mu = [1 \ 1 \ 1]^T$ can be reached.
- Build the reachability tree. Is the marking $\mu = [0 \ 2 \ 0]^T$ reachable?
- Find the cycles of operation for this Petri net.

Let $a=2$.

- Discuss the following statement "This Petri net is strictly of level 3".
- Discuss the liveness levels for $a=0$ and $a \geq 2$. The analysis changes if $\mu_0 = [1 \ 0 \ 0]^T$?

Q5. Supervision: A recent trend in industrial automation consists in replacing cabled by wireless communications. The next figure (left side) describes a control loop composed by an actuator and a sensor, which is operated by a local PLC using wireless communications. The controlled system is remotely supervised by a SCADA system. One repeater ensures the bridging of the long distance between the operating room, running the SCADA system, and the PLC controlling the system.



Petri nets to describe a wireless link. The net on the right is an OR convergence followed by an OR divergence.

Legend: p_{x-y} = Sending a message from x to y
 $t_i(x-y), t_{i1}, t_{i2}$ = Start sending a message (1, 2 indicate different sources)
 $t_e(x-y), t_{e1}, t_{e2}$ = End of sending a message

The five elements composing the complete system, SCADA, Repeater, PLC/Controller, Sensor and Actuator, are interconnected by four wireless communication links, all using the same frequency channel. In the figure shown above (right side) are suggested two Petri nets to describe one node sending one message. The second Petri net allows sending one message given two alternative reasons.

- Describe the communications using one Petri net for each of the four message sending nodes. Consider that the initial marking is zero for all places.
- Using the method of place invariants, formulate one or more supervisors that interconnect the message sending nodes. Notes: (i) The Repeater can send a message to the PLC/Controller only after receiving a message from the SCADA system. (ii) The PLC/Controller can send a message after receiving a message from the repeater or from the sensor.
- Study the conservation of the complete Petri net using the reachability tree. Comment whether the conservation property found for the net is satisfactory for the application under consideration.
- Consider now that one wants to avoid collision of messages sent by the Repeater and the Sensor. Propose a supervisor based on place invariants to fulfil message collision avoidance.
- Indicate generalized linear constraints to enforce that the Sensor, the Repeater and the SCADA do not send a new message until the controller completes processing the message sent before. In this question is not necessary to detail the computation of the supervisor. Simply add the necessary arcs and places to the Petri net, and comment on the boundedness of the final Petri net.
- Comment the next sentence: "In this system, the OR convergence followed by the OR divergence can create non-safe places, but safeness can be re-obtained with additional linear constraints".

Q6. Safeness: Consider a Petri net $C = (P, T, D^+, D^-, \mu_0)$ where D^+ and D^- denote pre and post incidence matrices, μ_0 is the initial state and

$$\begin{aligned}
 P &= \{p_1, p_2, \dots, p_N\} \\
 T &= \{t_1, t_2, \dots, t_N\} \\
 D^- &= I_N
 \end{aligned}
 \quad
 D^+ = \begin{bmatrix} \vec{0} & 1 \\ I_{N-1} & \vec{0} \end{bmatrix}
 \quad
 \begin{aligned}
 N &\text{ is a natural number, } N \geq 3 \\
 I_N &\text{ denotes an identity matrix with} \\
 &\text{size } N \times N
 \end{aligned}$$

- Show that $\mu_0 = [1 \ 1 \ 0 \ \dots \ 0]^T$ makes the net not-safe. Suggest alternative initial markings (states) that make the net safe.
- Let $\mu_0 = [1 \ 1 \ 0 \ \dots \ 0]^T$. Compute a supervisor, (D_c, μ_{c0}) based in place invariants, that makes the net safe.
- Comment the statement: "If one entry of μ_0 is larger than 1, then one cannot make the net safe".
- Let $\mu_0 = [2 \ 0 \ \dots \ 0]^T$. Propose a supervisor that makes the places p_2, \dots, p_N safe.

PS: Do not forget to identify all sheets of paper.

Good Luck,
 José Gaspar