Industrial Processes Automation

MSc in Electrical and Computer Engineering

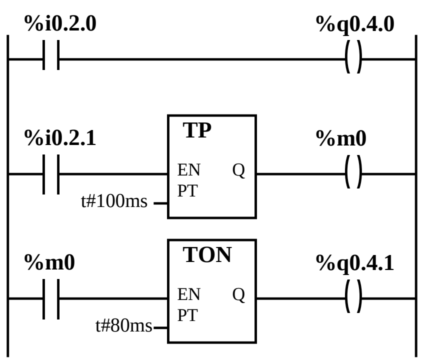
Winter Semester 2014/2015

2nd Exam, 31st January 2015

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. *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 **1msec+1msec** and each ladder instruction (contact read, coil write, timer) takes about **0.1msec**. The timers have preset values of **100msec** and **80msec**.



a) Indicate the scan period of the PLC.

b) Indicate the smallest time intervals, with probabilities larger than zero, for rising edges in the inputs, **%i0.2.0** and **%i0.2.1**, making changes in the outputs, **%q0.4.0** and **%q0.4.1**, respectively.

c) What changes in (b) if t#100ms changes to t#20ms?

Q2. *Logic function*: (a) Let a generalized XOR be defined as a function of N logic inputs and one logic output, where the output is TRUE if the number of TRUE inputs is odd. Propose a structured text program to implement a generalized XOR with ten inputs, %i0.2.1 till %i0.2.10, and the output %q0.4.1. (b) Do a Ladder program illustrating a (generalized) XOR in the case of two inputs and in the case of three inputs. (c) Consider: a 10 floors building has one ON/OFF switch at each of the floors; those switches are all connected to one PLC running a generalized XOR; the output of the generalized XOR is connected to one light outdoors, in the street. What happens to the street light if all switches are turned ON, one-by-one, and then all are turned OFF, also one-by-one?

Q3. *PLC input and output:*

a) Describe the output signals obtained in **%q0.4.1** and **%q0.4.2** by running the Structured Text program, shown in the right, in the case where %i0.2.1 is a single pulse with duration much longer than the scan cycle.

b) Modify the program to change 200 times less frequently the output **%q0.4.2**. Use just IF-THEN-ELSE and arithmetic instructions.

```
IF FE(%i0.2.1) AND %i0.2.1 THEN
  %q0.4.1 := NOT(%q0.4.1);
END_IF;

IF RE(%i0.2.1) AND %i0.2.1 THEN
  %q0.4.2 := NOT(%q0.4.2);
END_IF;
```

Q4. *Petri net properties:* This problem focus on Discrete Event Systems analysis tools studied on the course, for the Petri net defined as C=(P, T, A, w, μ_0) with

$P = \{p_1,p_2,p_3,p_4\}$, $T = \{t_1,t_2,t_3,t_4\}$,

$A = \{(p_1,t_2), (t_2,p_1), (p_1,t_1), (t_1,p_3), (p_3,t_3), (t_3,p_3), (t_2,p_2), (p_2,t_3), (p_4,t_4), (t_4,p_4)\}$, $\forall_{a,b}\ w(a,b) = 1$,

$\mu_0 = [1\ 0\ 0\ 1]^T$

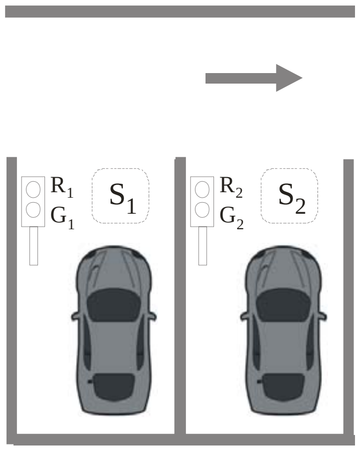
a) Draw the Petri net. Discuss the conservativeness, boundedness and safeness of the Petri net, resorting to a reachability tree. Discuss the liveness of each transition.

b) Draw a supervisor based on marking invariants, using generalized linear constraints, such that firing t_2 represents producing parts and firing t_4 represents consuming the produced parts. Between t_2 and t_4 there is a limited (finite) buffer allowing to store up to 5 produced parts, ready to be consumed.

c) Discuss the liveness of the transitions of the supervised Petri net considering the initial marking of place p_1 equal to 2 marks (the initial markings of the other places are not changed in this question).

d) Consider now the Petri nets $C_2=(P, T, A, w_2, \mu_{20})$ and $C_3=(P, T, A, w_3, \mu_{30})$ where $w_2= w_3= 2\ w$, $\mu_{20}=2\ \mu_0$, $\mu_{30}= \mu_0$. Compare the reachable sets $R(C, \mu_0)$, $R(C_2, \mu_{20})$ and $R(C_3, \mu_{30})$.

Q5. *Petri net modelling:* Consider the automatic traffic lights system shown in the next figure. The system is composed by two parking places (boxes) each one equipped with a two lights (Red and Green) semaphore, and a digital ON/OFF sensor to detect a car getting close to leave the box. Normally the semaphores have the Red light turned ON. When a car activates a sensor it is desired that the semaphore turns ON the Green light as soon as possible.



a) Draw an electrical diagram that details the automation solution. Include all sensors, all actuators and power supply.

b) Design a Petri net for the discrete event system described above. Each of the semaphores has three possible steps, namely *"Red light ON"*, *"Red waiting change to Green"* and *"Green light ON"*. Design a supervisor based on the place invariants such that at most one Green light can be turned ON.

c) Consider now just one semaphore and one sensor. Design a supervisor based on generalized constraints that changes the semaphore to the step "Red waiting change to Green" when there is a transition of the sensor from OFF to ON.

d) Considering the subsystem (c), show, using the method of matrix equations that the sensor can be turned ON, OFF and ON again without changing the respective RED light.

e) Design a supervisor that gives priority to the vehicle in the leftmost parking place (give priority to parking place 1 relative to parking place 2).

f) Discuss the generalization of the complete system to **N** parking places. In particular, discuss potential issues of generalizing one priority **{1→2}** to chaining with priorities all parking places **{1→2, 2→3, ..., N-1→N, N→1}**, where **i→j** denotes parking place **i** has priority relatively to place **j**.

Q6. *Combining Petri nets:* Let $\boldsymbol{\mu_a}$, $\boldsymbol{\mu_b}$, $\mathbf{D_a}$ and $\mathbf{D_b}$ denote the state vectors and incidence matrices of two Petri nets, **a** and **b**. (i) Show that an enlarged net with state $\boldsymbol{\mu=[\mu_a^T\ \mu_b^T]^T}$, running the two nets simultaneously, has an incidence matrix which is a function of the other two matrices, i.e. $\mathbf{D=f(D_a, D_b)}$. (ii) Consider now the addition of some extra arcs $\mathbf{(t_{ai}, p_{bj})}$ and $\mathbf{(t_{bk}, p_{al})}$ linking transitions of **a** to places of **b**, and transitions of **b** to places of **a**. What changes in **D**? (iii) Apply the results to the case where $\mathbf{D_a=[-1\ \ 0;\ 0\ \ -1]}$ and $\mathbf{D_b=[-1]}$ and one wants to add arcs $\mathbf{(t_{a1}, p_{b1})}$ and $\mathbf{(t_{b1}, p_{a2})}$. Draw the Petri nets before and after adding the two additional arcs.

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

Good Luck,

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