# Industrial Processes Automation

MSc in Electrical and Computer Engineering
Spring Semester 2018/2019
1st Exam, 11th June 2019

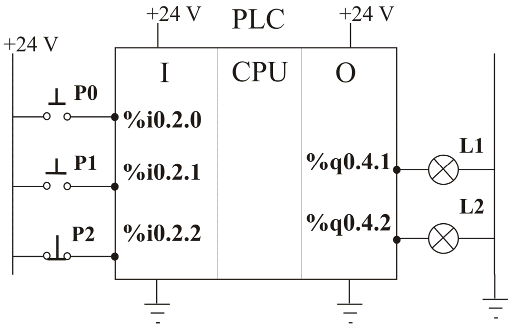
---

*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.** *Latch logic:* Consider the hardware diagram in the figure, where P0 and P1 are normally open push buttons and P2 is a normally closed push button. (i) Using just hardware addresses, **%i0.2.0**, **%i0.2.1**, **%i0.2.2**, **%q0.4.1** and **%q0.4.2**, write a **Ladder** program so that push and release **P0** turns ON **L1** and **L2**, push and release **P1** turns OFF **L1** and push and release **P2** turns OFF **L2**. (ii) Write in **Structure Text** a program with the same objectives. (iii) Write a logic table detailing how **%q0.4.2** depends on its inputs.

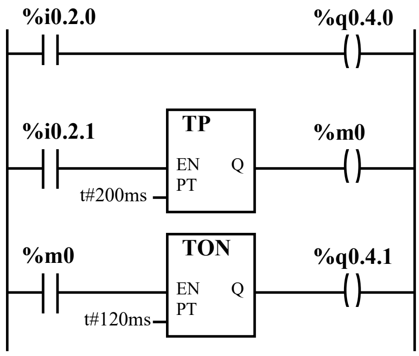



**Q2.** *Scan cycle:* Consider that the ladder diagram in the next figure is the single code run by a PLC, in a MAST section configured to be cyclic. The PLC input and output take **0.6msec+0.6msec** and each ladder instruction (contact read, coil write, timer) takes about **0.1msec**. Timers preset values are **200msec** and **120msec**.

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#200ms changes to t#100ms?




**Q3.** *Data logging into the PLC memory:* (i) Write a *Structured Text* subroutine to store at each run 16 binary inputs %i0.3.0 till %i0.3.15, into a location of a buffer of 16-bit words, namely %MW100 till %MW299. You can use additional auxiliary variables. (ii) Considering a scan cycle having a period of 1ms, how long will the PLC take to completely fill the buffer saving all the 16 binary inputs? (iii) In order to extend the total time logged propose a program modification to store data only once at each 100 scan cycles.

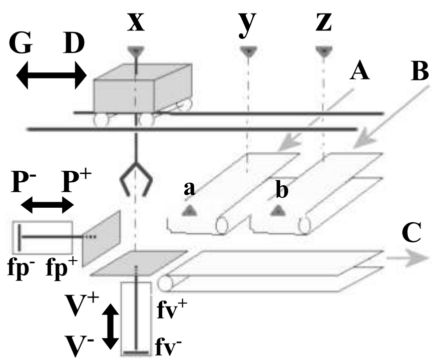
**Q4.** *PN model.* Consider the system in the figure. Conveyors **A** and **B**, are controlled by another system, and bring parts to this system. Sensors **a** and **b** detect parts ready to lift. Hanging crane, commanded with **D** (droit) e **G** (gauche), uses sensors **x**, **y** and **z** to detect crane over the base, over **A**, or over **B**, respectively. Clamp of the crane grabs and releases parts with commands **PP** and **DP**. Limit switches **fpp** and **fdp** indicate grabbed and released part. A holding platform moves up or down with commands **$V^+$** or **$V^-$**, and has two extreme positions, top and bottom, detected by switches **$fv^+$** and **$fv^-$**. Part release can only be done having the holding platform up. A part is pushed with command **$P^+$**. **$P^-$** retracts pusher. Limit switches **$fp^+$** and **$fp^-$** indicate max and min pushing positions. Pushing and elevating cannot happen simultaneously. The output conveyor, **C** is always ON.

a) Consider a PLC solution to automate the system. Draw an electric diagram indicating sensors and actuators.

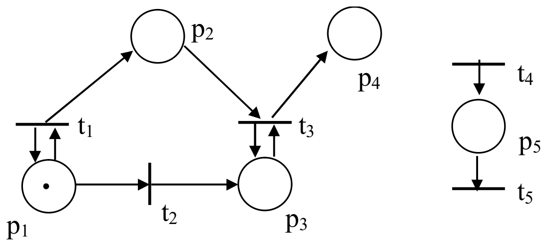
b) Propose one Petri net to represent the process of starting with a part **a** or **b** arriving, and cart at **x**, platform at **$fv^-$** and pushing effector at **$fp^-$**. Describe the meaning of places and transitions.

c) Draw the reachability tree. Study the properties coverability, safeness, boundedness, conservation and liveness.

d) Prove that the Petri net does not move the platform up (**$V^+$**) and at the same time have the pushing effector moving right (**$P^+$**).



**Q5.** *Properties and Supervision:* This problem focus on Discrete Event Systems analysis tools studied on the course, for the Petri net defined in the figure.




a) Discuss the liveness level of the transitions.

b) Using the method of matrix equations, prove whether or not are reachable the states (0,0,1,N,0), N=1 or N=2. Can one infer coverability from these states?

c) Design one supervisor to impose that the place $p_5$ cannot have more than 10 marks.

d) Design a supervisor based on marking invariants, using generalized linear constraints, such that firing $t_3$ represents producing parts and firing $t_4$ represents consuming the produced parts. The transition $t_3$ is allowed to fire up-to 3 times before being put on hold, waiting for some consumption done by $t_4$. Draw the supervisor just determined on the Petri net. Comment any possible change on liveness.

e) One may conjecture that the constraints associated to the sequence or quantity of firings can be rewritten with simple linear constraints by <u>adding an arc and an auxiliary place</u> at the output of the transitions under consideration. Try to repeat (d) using this conjecture.

f) Design one supervisor to impose that each firing of transition $t_5$ allows at most consuming one mark from the place $p_5$.

**Q6.** *Petri net simulation.* Many Petri net simulators give priority to the lowest numbered conflicting transition. Let $D^-$ and $D^+$ denote preconditions and pos-conditions matrices, and let $q$ denote a firing vector. Using matrix operations, propose $f_1(.), f_2(.)$ and $f_3(.)$, to obtain a new Petri net characterized by $D_2^- = f_1(D^-)$, $D_2^+ = f_2(D^+)$ and $q_2 = f_3(q)$ such that the original effects of transitions are kept but the new net gives priority to transition $t_3$ and keeps the sorting of the others, i.e. the evaluation order is $t_3$, $t_1$, $t_2$, $t_4$, $t_5$, ... , $t_N$ .

**Q7.** *Petri net supervision:* Let **M** denote a Petri net which is described by its incidence matrix $\mathbf{D_p = D_p^+ - D_p^-}$ and initial marking $\boldsymbol{\mu_{po}}$.

a) What is the expression of a supervisor, $\mathbf{D_c}$ based on place invariants with linear constraints $\mathbf{L\mu+Fq+Cv\leq b}$, when **L** and **C** are null? Show also $\mathbf{D_c^+}$, $\mathbf{D_c^-}$, and $\boldsymbol{\mu_{co}}$. Use the notation $\mathbf{F^+ = max(0,F)}$ and $\mathbf{F^- = max(0,-F)}$.

b) Consider a net $\mathbf{D_p^+ = I_N}$, where $\mathbf{I_N}$ is an identity matrix of size N, and $\mathbf{D_p^-}$ has all entries zero. Do a graphical representation of the supervisor obtained in the conditions of (a) special case $\mathbf{F= I_N}$. and $\mathbf{b= [b_1 \ldots b_N]^T}$.

c) Consider again a general **M** and one single $\mathbf{Fq \leq b}$ constraint on a single transition **j**. In other words, **b** is a scalar and only the entry **j** of **F** is not zero. (i) Write expressions indicating upper bounds to the maximum **consumed** and **created** marks by firing the transition **j**. Do not include the supervisor contribution in the expressions. (ii) Indicate how to upper bound the number of marks consumed by firing **j**. (iii) Discuss whether nonzero lower bounds can also be found.

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

Good Luck,
José Gaspar