Industrial Automation, Communication and Data Management

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SOLUTION

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Consider a robot in interaction with a human as in the picture:

1. Explain what collaborative robotics is and why it is considered important for the small and medium enterprises.

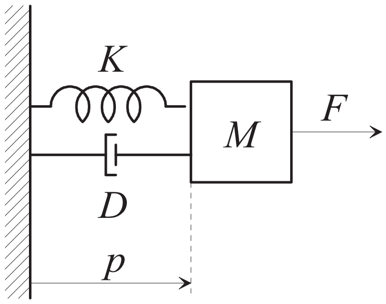
   In collaborative robotics, humans and robots are cooperating at the same task without protective fences or other kind of barriers (laser scanners, optical barriers, etc.). It is a mode of interest for SMEs because of the easier installation of the robot (reduced footprint, no need for complicated infrastructure for safety purposes), the decrease of the deployment time, and the easier interfaces.

2. List the collaborative modes allowed by the safety standards.

   The safety standards (ISO 10218) lists four collaborative modes:

   - Safety-rated monitored stop
   - Hand guiding
   - Speed and separation monitoring
   - Power and force limitation

3. Consider now the robot in contact with the environment (for example the human). In a simplified analysis, we can represent the situation with a mass-spring-damper system as in the picture:



Write the equations of the dynamic system that corresponds to the mass-spring-damper system.

The dynamic model of the mechanical system can be written as:

$$M\ddot{p} + D\dot{p} + Kp = F$$

If we choose as state variables $x_1 = p$ (position) and $x_2 = v$ (speed), as input variable $u = F$ (force) and as an output variable $y = p$, position, the corresponding dynamic system is:

$$\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= -\frac{K}{M}x_1 - \frac{D}{M}x_2 + \frac{1}{M}u \\ y &= x_1 \end{aligned}$$

4. Derive the expression of the transfer function of the mass-spring-damper system. Explain under what conditions on the parameters the system is stable but not asymptotically stable.

   Applying Laplace transform to all the equations, we easily obtain the expression of the transfer function:

$$G(s) = \frac{1}{Ms^2 + Ds + K}$$

   In order for the system to be stable, but not asymptotically, it shall have an eigenvalue (or pole of the transfer function) with zero real part and no eigenvalues with positive real part. This happens when either $K = 0$ or $D = 0$.

5. The robot exports information towards the backhand via MQTT. Namely, the robot mounts a MQTT client publishing on the following topics with the following features:

   - topic 1: *operation-time*: cumulative time the robot was moving upon switching on; publication frequency f_1=1[Hz], message size l_1=4[byte]
   - topic 2: *stall-time*: cumulative time the robot was still upon switching on; publication frequency f_2=1[Hz], l_2=4[byte]
   - topic 3: *displacement*: position in a three-dimensional space of the robotic arm; publication frequency f_3=5[Hz], l_3=12[byte]

- topic 4: *processed-items*: number of processed items/operation; publication frequency f_4=1[Hz], l_4=4[byte]
- topic 5: *acceleration*: current acceleration along the three axes (x, y, z) of the robotic arm number of processed items/operation; publication frequency f_5=5[Hz], l_5=12[byte]

What is the data rate of the MQTT flow generated by the robot? Comment on possible wired communication technologies which can be used to interconnect the robot (MQTT client) with the back-hand (MQTT broker) clearly highlighting advantages and limitations. Assuming that the MQTT client is connected to the MQTT broker via CAN bus, how many other MQTT clients of the same type (topics, frequencies and sizes) could be connected to the same broker via the same BUS?

The data rate generated by the MQTT client is given by:

$$R = f_1 l_1 + f_2 l_2 + f_3 l_3 + f_4 l_4 + f_5 l_5 = 1.056[kb/s]$$

If CAN bus is used as communication technology, knowing that the nominal rate of CAN bus if 1[Mb/s], the same BUS could in principle service ≈ 1k similar MQTT clients.

6. Comment on the main differences (advantages and disadvantages) between random-based and scheduled channel access control approaches. Mention at least two communication technologies for each one of the two classes.

   - Random Access Control Protocols: devices access the shared channel opportunistically and randomize the consecutive transmission attempts if collisions happen; collision are not avoided but wise recovery strategies are put in place to lower the collision probability of retransmitted information; good at low/medium traffic load; generally speaking of easier implementation than scheduled access approaches; sample technologies: Ethernet, WiFi, CAN Bus, IEEE 802.15.4
   - Scheduled Access Control Protocols: shared resources and sliced and dedicated to different devices/transmissions; collisions are avoided a priori; good when tight bound/requirements/-determinism on performance are required (data rate, delay); generally speaking more complex than random access schemes; sample technologies: IEEE 802.15.4, ProfiBUS.

7. Describe the network topologies supported by the IEEE 802.11 standard.

   - Basic Service Set: star topology with the Access Point at the very center
   - Ad Hoc: meshed networks with cross-traffic allowed
   - Extended Service Set: multiple BSSs interconnected via a Distribution System

8. Give some suggestions on how can ontologies be useful in data integration.

   - To support automatic understanding of the semantics of the instances for automatic entity resolution and data fusion.

- To support automatic understanding of the semantics of the schemas for schema integration.
- Using an ontology as global schema instead of a relational one
- To support (semi) automatic wrapping of the data sources

9. **PoliRobots** is a startup specialized in high precision welding. Since the revenue from high precision manufacturing is very high, one robot is enough for allowing *Polirobots* to remain profitable on the market. **UniRobots** is a big company specialized in welding too. Although *UniRobots* is not equipped to carry out high precision welds, *UniRobots* owns 100 robots which assure a big revenue as well.

   When an error occurs in one of *UniRobots*' robot welders a message is immediately sent to the control room. If more than one error occurs, a different message for each error will be sent. For *PoliRobots*, instead, a report is sent to the control room every 10 minutes. The report contains all the errors that have happened in the 10 minutes before (in case non error has occurred the report is sent anyway).

   The two companies have decided to merge into a unique one in order to be able to process orders that require both precison and standard welding more profitably. The CEO of the new company, **UniPoliRobots**, has just hired you to integrate the relational databases of the two original organizations into a unique relational database. You must perform the integration ensuring to lose the least possible amount of information.

   The original relational schemas of the two sources are reported below.

   PoliRobots:

   REPORT (ID, dateTime, #ofFaults)

   REPORTFAULT (reportID, faultID)

   FAULT (ID, description, solution, responsibleOperatorID)

   UniRobots:

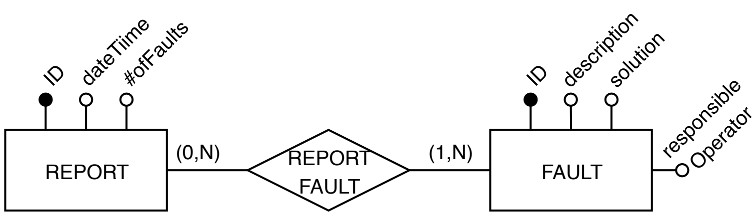
   MESSAGE (robotID, dateTime, errorCode) *//robotIDs are R001, R002, ..., R100*

   ERROR (code, description, solution, personInCharge, urgency)

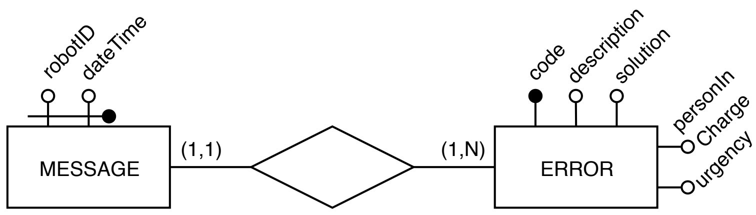
   You can assume everything in the two sources to be disjoint.

   (a) **Source schema reverse engineering**. Provide, for each input data source, the reverse engineering from the logical schema to the conceptual model (ER graph).

   PoliRobots:

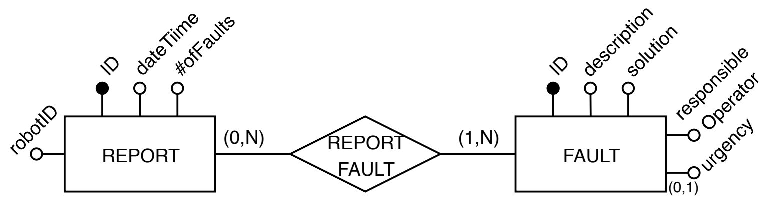


UniRobots:



(b) **Schema integration**. Design an integrated global conceptual schema (ER graph) for UniPoliRobots capturing all the data coming from both PoliRobots and UniRobots (if you find it useful you can draw the conflict table, although it is not required nor it will be evaluated).

UniPoliRobots:



(c) **Mapping definition**. Write the GAV mapping between the schema of UniPoliRobots and the two sources using SQL just for the table UniPoliRobots.REPORT

UniPoliRobots.REPORT:

```
CREATE VIEW UniPoliRobots.Report (ID, RobotID, dateTime, #ofFaults) AS
(
    SELECT KeyGenReport(ID, 'PoliRobots'), 'R101', dateTime, #of-
    Faults
    FROM PoliRobots.Report

    UNION

    SELECT KeyGenReport(robotID || dateTime, 'UniRobots'), robotID,
    dateTime, 1
    FROM UniRobots.Message
)
```