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A control-monitoring-maintenance framework based on Petri net with objects in flexible manufacturing system. Application to a robot-driven flexible cell.

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Abstract

The growing complexity of systems and the need for executing large projects have led to the development of complex flexible manufacturing systems (FMS) demanding specific control-monitoring architectures. The problem of failure occurrence tends to increase according to this complexity leading to time-consuming tasks as the localisation and repairing. The occurrence of failures during the exploitation stage can deeply modify the FMS performances or its availability. In this context, the maintenance integration into a control-monitoring system becomes an important issue, improving production time and minimizing unplanned costly breakdowns of FMS. We want to investigate the problem of triggering the maintenance, giving a useful decision support tool to evaluate the system availability since the control system's early design stage. It also results in improvement of the system's functionality in terms of efficiency, productivity and quality. This paper proposes a control-monitoring-maintenance architecture (CMM) for FMS based on Petri nets with objects (PNO), where stochastic rates are associated to the modelling of maintenance planning. This framework is based on a modular and hierarchic model structured in CMM modules. The integration is based on a development methodology in which the maintenance aspects and policies are taken into account from the conception (modelling) stage. These efforts acts as a basis for the control architecture of a robot-driven flexible cell, connected to the Ethernet-TCP/IP.

Keywords: Flexible manufacturing system, Supervision, Maintenance, Petri Nets.

INTRODUCTION

The flexible manufacturing system (FMS) can be considered as a system able to produce a wide variety of products under variable production conditions. Classically, this type of system is constituted by a set of elements and devices such as workstations, transport systems, programmable logic controllers, robots, and vision systems, connected to an industrial communication network. According to the manufacturing cell dimensions' increase, the control and supervision of its structure becomes more complex. Thus, to keep flexibility regarding its decision organization, a modular and hierarchic structure is proposed (Zamai *et al.*, 1997). Hierarchic architectures have been subject of many works during the last decades (Gershwin et al., 1988), (Giua & DiCesare, 1994), (Srinivasan & Jafari, 1993) and represent the framework basis of recent approaches concerning the control and monitoring of FMS (Jeng & Liang, 1998), (Pascal, 2000).

The demands for products with higher quality and competitive prices have led to the development of complex manufacturing systems. A consequence is that the number of failures tends to increase as well as the time required to locate and repair them. The occurrence of failures during nominal operation can deeply modify the FMS's performance or its availability. The improvement of production times and the minimisation of unplanned costly breakdowns of manufacturing systems becomes an important issue. The potential benefits of advanced manufacturing technologies (Gouvea *et al.*, 2000) to improve the strategic and competitive position of a firm have been shown to be closely sensitive to maintenance policies.

Maintenance and its integration with control and monitoring systems enable the improvement of systems functioning, regarding availability, efficiency, productivity and quality. Thus, it is possible to implement corrective and preventive actions, making repairs and servicing easier over the process elements, as well as a better control provision of tools and repair parts. In addition, integrated to a hierarchical supervision architecture it allows a better production scheduling and planning. Then, maintenance has to be planned and scheduled; planning the execution of maintenance tasks in accordance with a production plan. Thus, it is desirable that maintenance management studies be carried out from the system conception stage.

Different methods do not take maintenance into account as an isolated issue, but making it part of a supervision, control and monitoring system. Some works can be mentioned, such as the proposal of a maintenance model integrated into a supervision-control architecture performed by (Ly *et al.*, 2000), (Berruet, 1998), the maintenance and the reconfiguration aspects in (Tang & Zhou, 2001), and the modelling and management of maintenance policies proposed by (Simeu & Sassine, 2001), (Bondavalli & Filippini, 2004), (Mouss *et al.*, 2004), (Bérenguer *et al.*, 2004) by means of a stochastic Petri net and its extensions. Most of these approaches focus maintenance integrated into the monitoring systems in order to support the checking of resources and planning, where real time conditions are not pointed out. In (Jeng & Liang, 1998), a SMT (supervisor - monitor - trouble-shooters) framework presents an integrated design method for supervisory control, monitoring and troubleshooting, where real time aspects are considered.

Our approach looks into these two contexts (system conception stage and real time conditions in operation stage) through a CMM framework based on a development cycle methodology (DCM) proposed in (Loures & de Paula, 1999), (Santos *et al.*, 2004). The methodology consists of a cyclic three stages development – modelling, synthesis and implementation of the CMM structure. Maintenance aspects are also taken into account from the modelling stage (equipments indicators and maintenance policies rates) to the operating stage, where appropriate monitoring techniques feeds back the maintenance policies models triggered by the CMM structure. The proposed method is structured and modular. Following a classical top-down approach, it makes it possible to build simple models, which can be validated according the supervision level, and then interconnected in order to simulate the global system's behaviour.

One of the advantages of this approach is to consider the control - monitoring - maintenance functions simultaneously. Maintenance must be considered as one of the system's main functions, linked to the control and monitoring functions. The hierarchical and modular decomposition enables the implementation of maintenance policies, limiting its effects over the global system, allowing it to preserve its availability. Another advantage is the fact that, during maintenance actions, the monitoring is kept active and guarantees a coherent intervention in the process.

In this paper, the first section describes the control-monitoring architecture as a basic ground for the works. Then the integration of maintenance aspects is described, leading to the proposition of the CMM architecture. The next section presents an application of this architecture, which is under implementation in a real robot-driven flexible cell.

CONTROL-MONITORING-MAINTENANCE ARCHITECTURE

The real time control of complex Discrete Events Systems (DES) is classically solved by structuring the control system, both hierarchical and modular, on a four-level decision organization: planning, real time scheduling/supervision, co-ordination and local control (Chaillet *et al.*, 1997). The control functioning principle in a hierarchic context requires that only the module that has emitted a request for the lower level is able to modify it (Zamai et al., 1997). Therefore to modify a request that has been emitted, i.e., to reconsider the current control, the monitoring system must take the "request/report" sequence into consideration. Thus, a monitoring system following the control hierarchic levels and the maintenance policies needs is desirable (Ly *et al.*, 2000).

A message flow is established between the lower and the higher levels, informing maintenance parameters (e.g. cost functions, time and rate) when it is applied to the lower level. Then, the system's unavailability may be evaluated at the higher level. Inside a CMM node a communication process (synchronization) is also observed between a reference model (e.g. equipment, workstation), the control model and the maintenance model. This allows the information system to be updated through the monitoring system and the execution of maintenance policies.

Maintenance, according to (Ly *et al.*, 2000), is defined as a group of technical and administrative actions, including supervision and control operations, to maintain (*preventive/predictive maintenance*) or re-establish (*corrective maintenance*) an entity to a specific state or to specific safety operating conditions (RAMS – reliability, maintainability, availability and safety) (Ly *et al.*, 1999). Maintenance policies can be classified in four great categories (Simeu & Sassine, 2001): corrective, preventive, predictive and mixed. In all four cases, triggering a maintenance operation is a decision process based on the state (measured or estimated) of considered resources. The opportunistic maintenance (Bérenguer *et al.*, 2004) may be also considered by modelling maintenance operations grouping procedures, which are used to take advantage of scale economies due to economic or technical dependences between components (e.g. a maintenance operation on a component triggers the maintenance of the complete line).

The triggering of maintenance tasks through a continuous decision process inspired us to enrich the CM module (Zamai *et al.*, 1997) with a maintenance module and then to define the *control-monitoring-maintenance (CMM) model*, as shown in Figure 1.

Control-Monitoring module

First, let us consider the control-monitoring module. Each node is made up of the following elements:

- *Control Model*: comprises the operation sequence to be executed, which corresponds to a specific process handling.
- *Reference Model*: it is a process model that describes its possible states. The module's state is verified at the moment of a control request and at the moment a process signal (report) is acknowledged. The block's essential role is to continuously maintain the most perfect image of the real process's state.

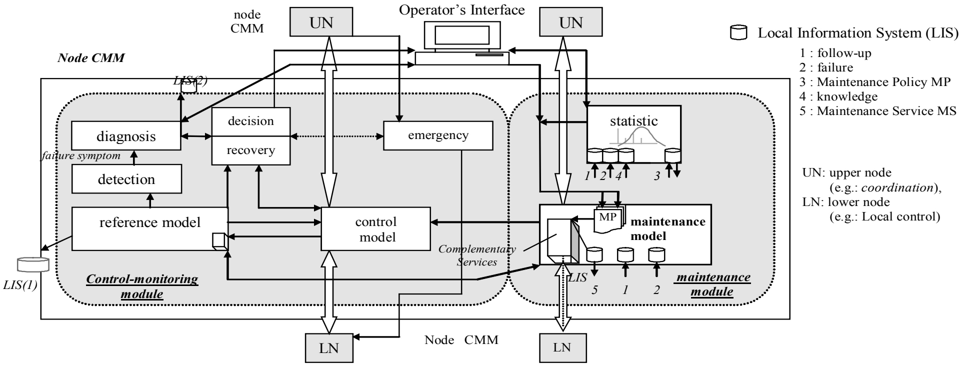


Figure 1. Control-Monitoring-Maintenance (CMM) Module

- *Detection*: the reference model is connected to the control model – it evolves in parallel and in real time during current operations of the process. At the moment in which the control model emits a request to the process, e.g.: starting an operation, a request is simultaneously transmitted to the reference model, which verifies the state's consistency, and estimates a temporal window for a process event to occur (end of operation). A *direct control monitoring* is characterised. If the control model within the allocated temporal window receives the report issued from the process, the control and the process model evolve simultaneously. Otherwise, the reference and control models can no longer evolve. At this moment it is possible to conclude that a process fault (equipment breakdown) just occurred, based on this non-consistent event, or based on a temporal signature that characterizes a failure evolution (in a *process indirect monitoring* approach). Moreover, the temporal causality observation of the events allows a progressive degradation evaluation of the manufacturing functions, which lead to a deviation of the production flow (in an *indirect predictive monitoring* approach). In fact, process reports are temporally analysed, regardless of the orders previously sent by the control part. In case of misbehaviour (a time drift on the events report), symptoms are generated and sent to the diagnostic function. The diagnosis module is thus required. Critical symptoms are also sent to error recovery in order to determine which actions have to be immediately performed to guarantee human and equipment safety.

- *Diagnosis*: it carries out the identification of the incident to which symptoms have been acknowledged. The diagnosis is generally broken down to three sub-tasks: *localization* (to find a functional sub-set of failing process components), *identification* (to refine localization by identifying the origin of a failure) and *prognosis* (to determine the consequences of a failure and to analyse its potential consequences and to prepare data required by the recovery function). The diagnosis is simple when it deals with a non-ambiguous symptom; even though it may also need a more sophisticated treatment using, for instance, an information system that completes the information that reports the absence of a process report (Chaillet *et al.*, 1997). The diagnosis engine is based on an algorithm that interprets the causal temporal signatures that characterize the different failures. The linear logic associated to a time fuzzy Petri net may be utilized as in (Künzle *et al.*, 1999).
- *Recovery decision*: its role is, according to diagnosis information (prognosis), to modify the control models, activate urgent procedures, trigger recovery procedures and, finally, decide about the propagation of failure treatment to the upper level.
- *Emergency*: provides the possibility, for the decision block, to immediately take action over the process, carrying out pre-defined and priority sequences (re-start, setting idle positions, etc).
- *Interface operator*: it is the user interface that allows the dialogue with a human operator every time his intervention is necessary. The operator has a central decision role.

The *monitoring process* follows a detection-diagnosis-recovery sequence. A confinement and propagation mechanism from the decision block decides if the fault is treated at the proper level (confinement) or if a request must be emitted to the upper level node (propagation).

The maintenance module – the CMM node

Figure 1 shows the architecture of a *control-monitoring-maintenance model* (CMM) at a given level. The insertion of the maintenance module did not modify the functionality of the described CM module's elements.

First, it is necessary to point out the purpose of the *decision* and *recovery* block concerning the CMM structure. As soon as this block is requested by the diagnosis block, it triggers different actions. If there is a risk to the operator or the process, the decision block triggers an emergency procedure and informs the upper level. Otherwise, it establishes a recovery point and the specific sequence makes it possible to access it. If the expected state is not coherent with the upper level's vision, the decision block informs about it; if no recovery process can be established, it sets the system to a maintenance state, informs the upper level and requests the operator. This is the *corrective maintenance* scenario. In this case it is necessary to "repair the defective material", i.e., eliminate fault effects in order to reach the system's regular operation status. This requires human intervention. The operator can access a maintenance module that offers a group of maintenance operations that are not necessarily the same as those of the control block. The control module remains in a blocked state during all intervention period. At the end of the maintenance activity, the system is redirected to a coherent state concerning the control model by the maintenance module, which authorizes its evolution.

The maintenance module consists of two blocks: the *statistic block* and the *maintenance model*. The purpose of the *statistics block* is to use all information issued from the process and control (process data registering) to calculate, estimate and establish a preventive and predictive maintenance plan. It assigns to some transitions of the maintenance model Petri net a transition rate with exponentially distributed triggering time. Random planning of maintenance policies or failure and repair rates are so modelled. The operator is informed that a preventive/predictive maintenance operation has become necessary. This block is supported by a *Local Information System* (LIS). The LIS is updated by different CMM module blocks and by external information (operators, equipment information, maintenance policies, etc). Concerning maintenance, it presents the following structure:

- *LIS* (*policy*): updates the maintenance intervention database. This registering makes future interventions easier;
- *LIS* (*knowledge*): contains information supplied by operators (experience return), information and indicators about the production system (MDT, MTTF, MTTR, MUT) supported by physical measures from dedicated sensors (vibration, temperatures, etc.). The prognosis function is performed to estimate the remaining life-time of the element leading to a direct predictive maintenance policy;
- *LIS* (*follow-up*): memorizes all control activities and plant events reports and their start and end dates; it enables to keep a control and a process image so as to support the diagnosis algorithm when a failure occurs or a deviation symptom comes about (indirect predictive maintenance policy);
- *LIS* (*failure*): memorizes information about detection, diagnosis and the decision regarding a failure.

In addition, it can be used to update the reference models' temporal windows in order to estimate the average operation time, so as to have a more precise representation of the process and to support the prognosis function.

The *maintenance model* suggests a group of services and/or sequences of specialized operations that are linked to a maintenance policy and that are not necessarily foreseen by the control under regular operation. A similar context may be found in (Ghoshal *et al.*, 1999), where some concepts were taken into account and adapted to our approach.

Maintenance is triggered by the operator after an unresolved fault case – it is the *corrective maintenance* policy or when triggered by the statistic block - it is the *preventive and predictive maintenance*. When maintenance is required (corrective, preventive or predictive), the modules' maintenance model inhibits all pre-set operation sequences (regular operating conditions) at the control model level. At this point the maintenance module takes up control of the process. The maintenance mode is, therefore, synchronized with the evolution of the reference model. In fact, it is important to take account of the process restrictions in order to provide a safety mechanism, making it impossible for the operator to trigger operations that are not in conformity with the process state. It is necessary to mention that, prior to any maintenance procedure, an image of the control state is captured by the local information system (LIS) to replace, after the intervention, the process and control into a coherent state.

The communication with the upper level consists in informing the maintenance state and, eventually, the estimated duration to implement the maintenance policy. This information is received by the upper maintenance module (node), which informs the control-monitoring module. The acknowledge of this information by the upper CMM module may lead to a reconfiguration process (Berruet, 1998), (Silveira *et al.*, 2000). The reconfiguration process consists of updating the FMS's architecture's flexibility to compensate the lack of services caused by the faulty resource. This can result in a simple displacement of the operations' sequence or the use of available resources, thus enabling the expected services.

APPLICATION TO A ROBOT-DRIVEN FLEXIBLE CELL

The flexible cell

The manufacturing cell is composed by four *working stations* served by a *conveyor system* and its *pallets* with parts to be treated. Each working station has a *robot* and a *vision system,* two parts stocks and a working desk. This cell is represented in Figure 2. This working station can perform assembly, disassembly, control and calibration operations.

The cell's *functional organization* is hierarchic and modular, structured in 5 levels: i) *Robots and local control*, vision systems and conveyor system zones at the lowest level; ii) The *coordination level* is organized into a working stations *local coordination* (robot, vision system), a *conveyor system coordination* (organized and controlled by 5 modules) and a general coordination; iii) At the highest levels, the *supervision, scheduling* and *planning* (production management).

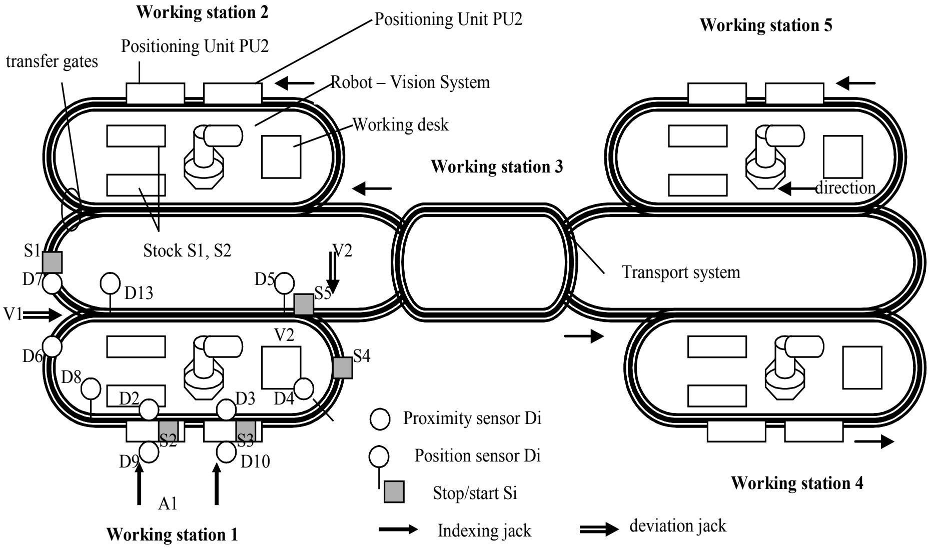


Figure 2. Robot-driven flexible cell

The CMM module

The *functional* structure of a local coordination CMM node is shown in Figure 3. It proposes a more flexible structure to allow the choice and the configuration of a service issued from the upper level (taking a set of pre-defined services into account). Thus, the node's functionality and flexibility increases by offering of this set of services in a layer and modular organization, leading to a local 'virtual hierarchy'. This results in a better interface with the upper (*general coordination*) and lower levels (*local control of robots and vision systems*). All this functionality is extended to the maintenance module.

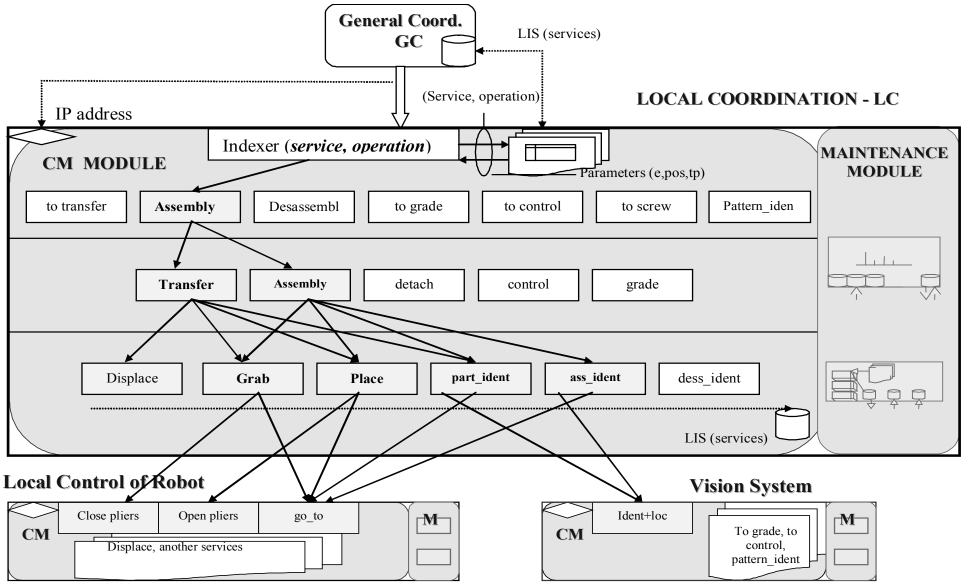


Figure 3. The CMM module

Figure 3. The CMM module

Let us start with the *assembly* of a spare part issued from the stock, on top of another part located above a working desk. The *control, reference and maintenance* models concerning this coordination level are described in Figure 4, and make up the CMM coordination module.

The representation of these models is based on *Petri Nets with Objects (PNO),* where the tokens hold the information (token attributes). The interpretation associated to transitions based upon these attributes leads to the execution of tests and actions (Zamai et al., 1997). In the maintenance PN model, stochastic rates are associated to some transitions that model the random planning of a maintenance policies (preventive maintenance - β_{pm}) as well as failure and repair/maintenance intervention rates (failure/corrective maintenance - λ_{cm}, duration and preparation rate - τ_c, τ_p, repair / maintenance intervention - µ) . A Markov graph (array) is considered in the statistic block for a numerical simulation and evaluation.

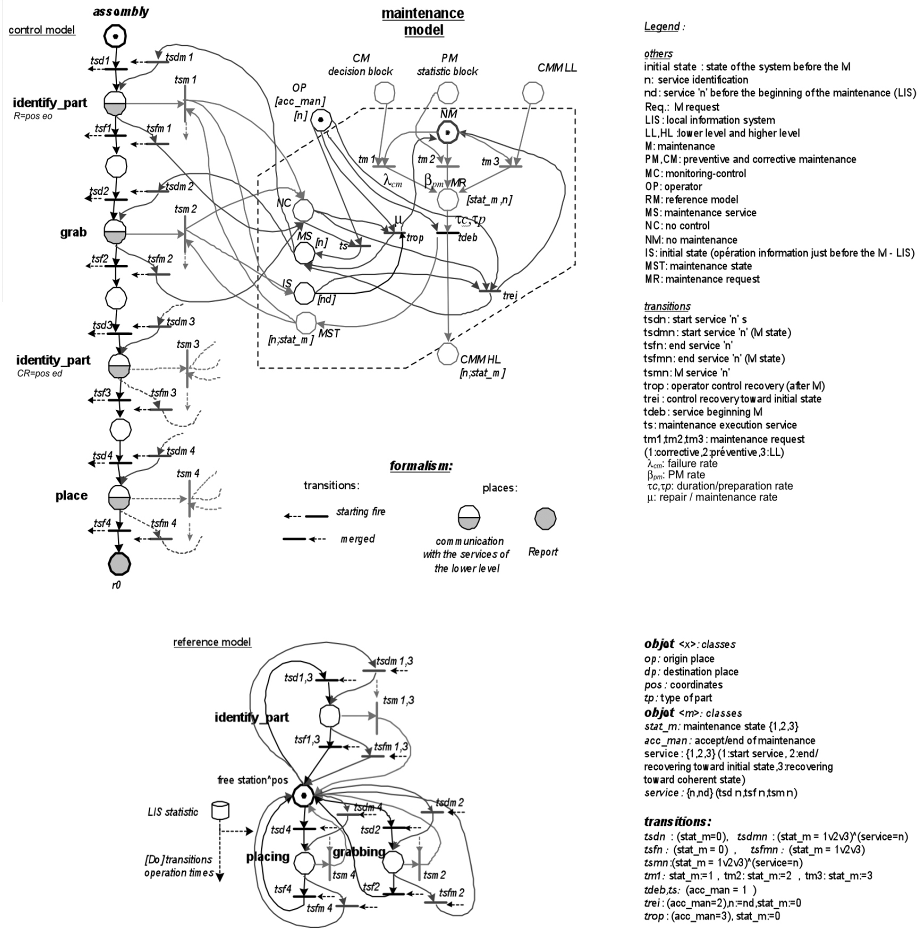
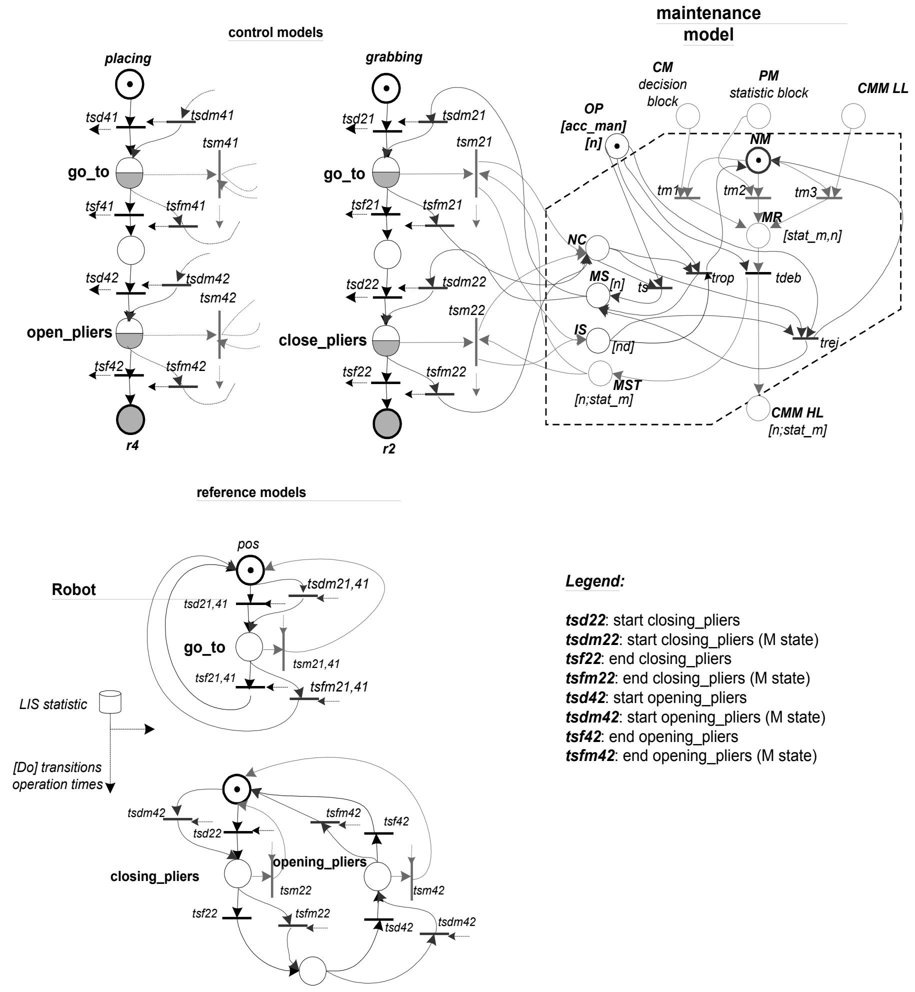

assembly
control model
tsd1
tsdm 1
tsm 1
identify_part
R=pos eo
tsf1
tsfm 1
tsd2
tsdm 2
tsm 2
grab
tsf2
tsfm 2
tsd3
tsdm 3
tsm 3
identity_part
CR=pos ed
tsf3
tsfm 3
tsd4
tsdm 4
tsm 4
place
tsf4
tsfm 4
r0
maintenance model
CM decision block
PM statistic block
CMM LL
OP [acc_man] [n]
NM
tm 1
tm 2
tm 3
λcm
βpm
MR
[stat_m ,n]
NC
μ
trop
τc,τp
tdeb
MS [n]
ts
IS [nd]
trei
[n;stat_m] MST
CMM HL [n;stat_m]
formalism:
transitions:
starting fire
merged
places:
communication with the services of the lower level
Report
Legend :
others
initial state : state of the system before the M
n: service identification
nd: service 'n' before the beginning of the maintenance (LIS)
Req.: M request
LIS: local information system
LL,HL :lower level and higher level
M: maintenance
PM,CM: preventive and corrective maintenance
MC: monitoring-control
OP: operator
RM: reference model
MS: maintenance service
NC: no control
NM: no maintenance
IS: initial state (opération information just before the M - LIS)
MST: maintenance state
MR: maintenance request
transitions
tsdn: start service 'n' s
tsdmn: start service 'n' (M state)
tsfn: end service 'n'
tsfmn: end service 'n' (M state)
tsmn: M service 'n'
trop : operator control recovery (after M)
trei : control recovery toward initial state
tdeb: service beginning M
ts: maintenance execution service
tm1,tm2,tm3 : maintenance request
(1:corrective,2:préventive,3:LL)
λcm: failure rate
βpm: PM rate
τc,τp: duration/preparation rate
μ: repair / maintenance rate
reference model
tsdm 1,3
tsd1,3
tsm 1,3
identify_part
tsf1,3
tsfm 1,3
free station^pos
LIS statistic
tsdm 4
tsdm 2
tsd4
tsd2
placing
grabbing
tsm 4
tsm 2
tsf4
tsf2
tsfm 4
tsfm 2
[Do] transitions operation times
objot <x>: classes
op: origin place
dp: destination place
pos : coordinates
tp: type of part
objot <m>: classes
stat_m: maintenance state {1,2,3}
acc_man: accept/end of maintenance
service : {1,2,3} (1:start service, 2:end/
recovering toward initial state,3:recovering
toward coherent state)
service : {n,nd} (tsd n,tsf n,tsm n)
transitions:
tsdn : (stat_m=0), tsdmn : (stat_m = 1v2v3)^(service=n)
tsfn : (stat_m = 0) , tsfmn : (stat_m = 1v2v3)
tsmn :(stat_m = 1v2v3)^(service=n)
tm1: stat_m:=1 , tm2: stat_m:=2 , tm3: stat_m:=3
tdeb,ts: (acc_man = 1)
trei : (acc_man=2),n:=nd,stat_m:=0
trop : (acc_man=3), stat_m:=0

Figure 4. CMM reference-control-maintenance models for coordination of working station

Let us consider the control model. The *assembly* service starts a sequence of low level services: *'identify_ part'* service, which identifies the part's location in order to recover it (offered by the vision system's local control), *'grabbing'* service which grabs and moves the part from and into a placing position, *'placing'* service which corresponds to the assembly part and *'grabbing'* service for the removal of the assembly part (offered by the robot local control (Figure 5)). The associated reference model represents the process restrictions (mutual exclusion of operations and estimated operational times).

Communication between these models is implemented by means of a transition fusion method: as soon as the service control model 'part_*identification'* is requested, which corresponds to firing transition *'tsd1'*, the *'tsd13'* transition, associated to transition *'tsd1'* at the reference model, is simultaneously fired (under the condition that its input place *'free_station'* is marked, meaning that the requested service is coherent with the process state). Therefore, the reference model evolves towards the *'part_identification'* state.



Legend:

tsd22: start closing_pliers
tsdm22: start closing_pliers (M state)
tsf22: end closing_pliers
tsfm22: end closing_pliers (M state)
tsd42: start opening_pliers
tsdm42: start opening_pliers (M state)
tsf42: end opening_pliers
tsfm42: end opening_pliers (M state)

Figure 5. Local command CMM models for robots

The request is transmitted to the lower level, in this case, the vision system's local control. If the lower level execution report is not received within a temporal window defined by the reference model, the reference and control models can no longer evolve. A failure is detected and the monitoring process is triggered (detection, diagnosis, recovery).

If the execution report is received within the temporal window, the control and reference models can evolve (simultaneous firing of *'tsf1'* and *'tsf13'*). The reference model evolves towards the *'free_station'* state and the control model can request the *'grabbing'* service. Therefore, a simultaneous firing of *'tsd2'* occurs in the control and reference models and the latter also changes to the *'taken'* state. The service request is transmitted to the lower level, in this case, to the robot's local control.

At this level, the control model carries out a sequence of elementary controls over the process: *'go_to'*, then *'close_pliers'* (Figure 5). Two reference models represent the process' behaviour associated with the pliers and the arm movement. The evolution of the control and reference models is made as described previously. When this last sequence operation (*'close_pliers'*) ends, an execution report of the *'grabbing'* service (*'cr2'*) is transmitted to the CMM module's upper level. Then, the *'place'* and *'grab'* services are executed.

Let us suppose that a failure is detected at the end of the final *assembly* part operation: the *'close_pliers'* end-of-execution report is not received within temporal window. Thus, the decision block requires a corrective maintenance action from the operator (*CM-tm1-MR* sequence at the maintenance model of the CMM module's local control).

The operator acknowledges the module in a maintenance state and the upper level is informed about it (*OP-tdeb-MST/CMM NS* sequence). At the upper level, this information will be taken into account by the decision block and by the operator, who will decide, or not, about also placing the module in the maintenance state (*CMM LL-tm3-MR-tdeb-MST*). The module's maintenance state means the suspension of the on-going operation and its registering due to its recovery (*MST-tsm22-NC/IS* sequence).

At this moment the operator is able to require services or operations available in the control model, or trigger operation sequences that are different from the regular control (*OP/NC-ts-MS-tsdmn*). The detection mechanism still considers the process' restrictions through the reference model (transitions *'tsdmn'* and *'tsfmn'*). Sequences, tests or maintenance operations depend on the operator's experience and can be formulated by means of a rule-based system (expert system). It is possible to use the local information system's (LIS) data as a reference: failures historic data, interventions maintenance policies adopted, MTBF, MTT indexes, etc. Considering our case, when failure at the *'close_pliers'* service is detected, the operator is able to request:

- pliers opening (*OP/HS-ts-MS-tsdm42-open_pliers sequence*), and if the end-of-execution report (opening/closure signal value is acknowledged and the strength sensor is in state 0) is received within the temporal window (leading to firing *tsfm42* and marking *NC*), it is possible to conclude that the opening/ closing pliers device is working.

- pliers repositioning (*OP/NC-ts-MS-tsdm21-go_to-tsfm21-NC* sequence) to make a pliers closing test with maximum safety;
- closing the empty pliers (*MS-tsdm22-close_pliers* sequence). If the end-of-execution report (value of the closing/opening signal is acknowledged and the strength sensor has an empty closing value) is not received within the time window, it is possible to conclude that the closing device is not working (interruption of the air supply, for example).

Once the failure is repaired, the operator is able to perform new tests, requesting a specific part in the stock (*'identify_part'* service of the CMM coordination module, after '*taking*' and finally '*placing*' it in the stock, for example). And finally, the operator must replace the control into a coherent state – to the breakdown initial state (registered by the *IS* location's stick), i.e., at the beginning of the *'taking'* service (*OP/NC/IS-trei-MS-tsdm2 sequence)* or proceed to the finalization of the suspended operation, before leaving it to the general control (*OP/NC/IS-trop-MS-tsdm2 sequence*). In both cases the reference models are equally replaced into coherent states. All interventions are registered in the Local Information Systems (LIS policy) to make future interventions easier.

CONCLUSION

This study presented a hierarchic and modular control-monitoring-maintenance architecture, organized in CMM modules. In each module the interaction of a control module, process's reference models (allowing the detection of failures) and a maintenance module (consisting of a maintenance model and a statistics module) can be observed. This module allows different maintenance policies to be carried out - corrective and preventive/predictive ones.

The statistics block, coupled to a local information system, enables the registration of all the information issued by the process and control, it estimates and establishes a preventive/predictive maintenance plan and helps the operator during a maintenance intervention. The maintenance model PN may simulate the system's stochastic behaviour when subject to failures and maintenance procedures and repairs.

The operator can access, via maintenance model, the services and operations offered by the control and can sequence them differently from the expected process. In addition, it is possible to, eventually, access services that are available, but are not being used in the current process. The evolution of reference models during the control stages and during the maintenance stage results in an assurance of a coherent use of the process. This integration process, the maintenance tasks integrated into the control and monitoring structure, are the main advantages of our approach.

The proposed architecture is actually being implemented in a robot-driven flexible cell, connected to the Ethernet TCP/IP. Therefore, it is necessary to study the problems presented in a remote maintenance context, e.g.: the remote configuration of the CMM modules, network and devices, as well as the reliability, safety and real time conditions. Moreover, the planning and scheduling levels will be considered in detail leading to the definition of interfaces with the CMM nodes.

The CMM architecture (its models) is based on a development cycle methodology that characterizes the following steps: modelling, analysis/simulation and implementation of the CMM modules. Then, the maintenance aspects may be taken into account from the concept stage to the operation stage of a flexible manufacturing system. The proposed modelling approach based on Petri nets allows a modular optimisation of the maintenance procedure.

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