# A Nervousness Regulator Framework for Dynamic Hybrid Control Architectures

**Jose-Fernando Jimenez, Abdelghani Bekrar, Damien Trentesaux and Paulo Leitão**

**Abstract** Dynamic hybrid control architectures are a powerful paradigm that addresses the challenges of achieving both performance optimality and operations reactivity in discrete systems. This approach presents a dynamic mechanism that changes the control solution subject to continuous environment changes. However, these changes might cause nervousness behaviour and the system might fail to reach a stabilized-state. This paper proposes a framework of a nervousness regulator that handles the nervousness behaviour based on the defined nervousness-state. An example of this regulator mechanism is applied to an emulation of a flexible manufacturing system located at the University of Valenciennes. The results show the need for a nervousness mechanism in dynamic hybrid control architectures and explore the idea of setting the regulator mechanism according to the nervousness behaviour state.

**Keywords** Nervousness · Dynamics · Hybrid control architecture · Switching · Multi-agent system

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# 1 Introduction

A dynamic hybrid control architecture (D-HCA) is a promising control model that adapts to complex system demands. ADACOR [7] and PROSA [16] are two of the most known approaches in D-HCA. In general, these architectures feature a reconfiguration property that adjusts the functioning of the system by tailoring the control solution according to the corresponding system needs. However, the dynamic characteristic of these architectures challenges the efficiency of this paradigm. During the reconfiguration process, the system may experience some instability resulting from an improperly synchronized evolution process [8]. In particular, this process lacks sufficient time to stabilize the solution and activate the benefits from the new configuration [15]. In this situation, the system is undergoing nervousness behaviour. For this paper, *nervousness behaviour* is a conduct of a whole or part of a system in which its decisions or intentions change erratically without leaving a sufficient time for stabilizing into an expected functioning. For example, in the flexible manufacturing system, the degree of nervousness behaviour in the system increases when the products change constantly its intentions of reaching a machine in an assembly system. Thus, it is crucial to control the nervousness behaviour of a system to avoid the unstable and chaotic behaviour in D-HCAs.

The paper proposes a framework of a nervousness regulator that handles the nervousness behaviour based on an indicator of nervousness. In addition, a classification of nervousness is created that responds to the necessity of dealing with different mechanisms according to the current nervousness behaviour of the system. The paper is organized as follows: Sect. 2 reviews the nervousness behaviour in dynamic systems. Then, Sect. 3 presents the general framework of a nervousness regulator for D-HCA. An instantiation of the framework applied to a case study of a flexible manufacturing system is presented in Sect. 4. Section 5 describes an experimental case study and illustrates the need for a nervousness regulator in D-HCA. Finally, Sect. 6 concludes the findings of this research and provides future research to be addressed.

# 2 Nervousness Behaviour: Literature Review

Nervousness behaviour in dynamic systems has several definitions. Initially, a nervous system was used to describe the perturbations occurring in the material requirement planning (MRP) systems. In this domain, the concept of a nervousness behaviour started as the changes of intentions, experienced by low-level entities, when the master schedule does not change significantly [13]. In this case, the nervousness is defined by the difference between the planning and the real execution of operations. Subsequently, the term evolved to the instability derived from internal/external changes or perturbations that cause the system process to be treated as an exception [2, 9]. However, the changes occurring on internal and external levels can be either great enhancement opportunities or extremely disruptive events for the system's behaviour [11].

In the D-HCA domain, the nervousness behaviour is present in the changes made in the control solution. In this sense, a D-HCA that avoids the nervousness behaviour must balance the tension of performing sufficient changes for reacting and enhancing the system's performance while maintaining a stable and safe evolution [1, 10]. In general, the condition that a system experiences nervousness behaviour is not a negative comportment. However, it is crucial to dampen the nervousness in order to avoid experiencing a nervousness state. When the system presents nervousness behaviour, the system reacts to internal and external stimuli erratically [3] and increases a non-coordinated solution towards the achievement of system objectives.

Thus, researchers have introduced the nervousness regulator to dampen this behaviour. Hadeli et al. [3] proposed a mechanism that assures that the perceived improvement in the system's evolution is good enough. The dampening of the nervousness is preventive and affects directly to change of agent's intentions. Another way to detect nervousness is to evaluate the tendency of a specific performance indicator [4, 5]. The authors propose a mechanism that monitors a nervousness indicator in different time windows. In this approach, the nervousness behaviour is avoided by monitoring the tendency of an indicator. As another example, Barbosa et al. [1] propose a nervousness control mechanism based on a proportional, integral and derivative (PDI) feedback controller to support the system dynamism. In this case, the threshold is not fixed and, due to the degree of nervousness, the regulator intervenes to keep the system's stability.

It can be seen from the literature reviewed that the nervousness behaviour is concentrated in the changes of agents in distributed architectures. Certainly, these changes influence the emergence behaviour of the system. However, the changes in the control architecture of the system's structure and its behaviour have not been properly explored simultaneously. Additionally, although researchers have focused on the detection and handling of the nervousness behaviour, very few solutions have been proposed to prevent and mitigate the occurrence of such behaviour. Therefore, we propose to include a nervousness regulator in a D-HCA that damps the instability derived from continuous structure/behaviour changes; a framework is conceived that partitions the regulation strategy according to the degree of nervousness.

## 3 Proposed Nervousness Regulator Framework in D-HCA

This section presents the proposed framework to control the nervousness behaviour in a D-HCA. The framework identifies four phases of the nervousness behaviour according to the nervousness state: prevention, assessment, handling and recovery. Figure 1 illustrates the framework's phases.

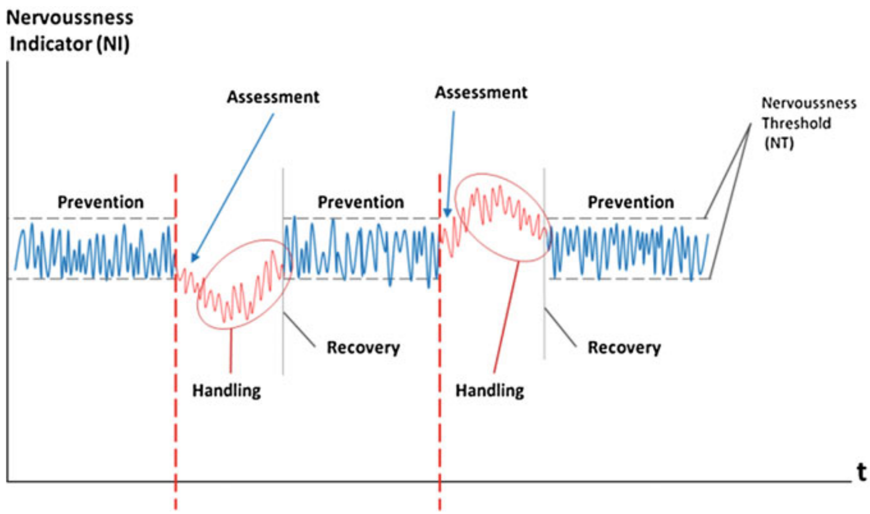



**Fig. 1** Phases of a system towards nervousness behaviour

The management of the nervousness behaviour is based on monitoring of the dynamic systems with a **nervousness indicator** (**NI**). This indicator shows the nervousness of the system by measuring the system stability. Additionally to this indicator, this framework defines a **nervousness threshold** (**NT**) as the maximum nervousness level allowed by the system during execution. Once the threshold is passed, the nervousness regulator starts functioning. This out-of-control event is addressed differently depending on the state of the nervousness behaviour. A framework consists of an iterative four-phase method used to control the nervousness behaviour of a system. Each phase is explained in Table 1.

**Table 1** Phases of the system towards a nervousness behaviour

| | |
|---|---|
| **Nervousness crisis prevention**:<br>1. Mitigate the risk of nervousness behaviour.<br>2. Establish auto-regulators that monitors and autocorrect the nervousness indicator.<br>3. Conditional-rules or heuristics. | **Nervousness crisis assessment**:<br>1. Discover the nervousness incident.<br>2. Establish evaluation methods that detect the incident by the infringement of threshold.<br>3. Statistic, data mining or forecasting methods. |
| **Nervousness crisis recovery**:<br>1. Stabilize the system and provide feedback to the prevention phase.<br>2. Establish a method to return to normal conditions<br>3. Feedback and re-tuning parameters (threshold) | **Nervousness crisis handling**:<br>1. Handle and calm the nervousness incident by reconfiguring.<br>2. Establish methods to damp the incident.<br>3. Simulation-optimization and tuning methods |

In D-HCA, the nervousness present in the system is due to the changes performed by a switching mechanism that modifies or reconfigures dynamically the structure and/or behaviour of the system to obtain a custom-built optimal configuration. However, in order to accomplish this objective, the system might switch constantly causing a nervousness event. In this paper, we focus on the nervousness crisis prevention phase of the nervousness regulator in order to prove the need for a mechanism in the system. In this respect, the nervousness control authorises or not the switching procedure depending on the nervousness threshold. An instantiation of the proposed framework focused on the prevention of the nervousness state is proposed in the next section.

## 4 Nervousness Regulator of a Flexible Manufacturing System

In this paper, a D-HCA of a flexible manufacturing system is modelled with a nervousness regulator. At first, the D-HCA constructed specifically for the case study is presented. Then, the inclusion of the nervousness regulator in the defined D-HCA is described. The D-HCA is modelled as a dispatching scheduler with an agent-based solution. While the scheduler is a MILP solution for a flexible job shop problem only for dispatching, the jobs are intelligent entities represented by agents within the simulation. The reason for using this solution responds to the idea of giving full autonomy to the agents for monitoring the changes of intentions during product execution.

### *4.1 The Case Study of a Flexible Manufacturing System*

The manufacturing system in the paper corresponds to a flexible manufacturing system (FMS) located at the University of Valenciennes (France) in the AIP PRIMECA lab. It consists of seven workstations (M1, M2, M3, M4, M5, M6, M7) connected by a flexible transportation system. Seven different assembly jobs (B, E, L, T, A, I and P) can be produced in the FMS and each has a sequence of operations including O1, O2, O3, O4, O5, O6, O7 and O8 to be executed. Each workstation can perform a subset of operations O*i*. The production starts when a holding-case is loaded in M1 in the moving shuttles for O7. Once the sequence of each job has been processed, the shuttle returns to M1 to be unloaded in operation O8. The AIP PRIMECA facility is modelled as a flexible job shop problem (FJSP) with material processing and handling flexibility. The manufacturing system layout, the sequence of operations for each job and the processing times for each operation in the AIP PRIMECA are available in the benchmark of Trentesaux et al. [14].

## 4.2 D-HCA of the Flexible Manufacturing System

The D-HCA of this paper is based on the governance mechanism approach proposed in Jimenez et al. [6]. This approach features an operating mode of a D-HCA as a specific parameterization that characterizes the control settings applied to the system. A switching mechanism, called governance mechanism, commutes the operating mode to reconfigure the architecture of the control system. The D-HCA that controls the FMS is organized as follows (Fig. 2):

**FMS Controlled system**: the general structure of the FMS is divided into two layers: a global and a local layer. While the global layer contains a unique global decisional entity (GDE) responsible for optimizing the release sequence of the production orders (scheduler), the local layer contains several local decisional entities (LDE) as jobs to be processed in the production order (7 jobs in scenario A0). In this approach, each decisional entity (GDE or LDE) includes its own objective and governance parameters. In this scenario, the objectives of the GDE and LDE are respectively to minimize the makespan at batch execution level and the completion of the next operation. The governance parameter in the GDE is the role of the entity for establishing the order release sequence and imposing these intentions to the LDE in the shop floor. The governance of each LDE is represented by the reactive technique that guides the evolution of the job through the shop floor. This evolution can be driven by a potential-field's (PF) approach [12] or by the first available machine rule (FAM). For this research, even though both PF and FAM techniques are part of the reactive approach in distributed systems, it is considered that the potential-field's approach assures higher performances while computing resource allocation depending on their availability and shortest route to the resources. For a better representation of the configuration, an operating mode vector that gathers all the governance parameters of the decisional entities is defined.

**Governance mechanism entity**: this switching mechanism is responsible for changing the governance parameters of the GDE and LDE through the operating

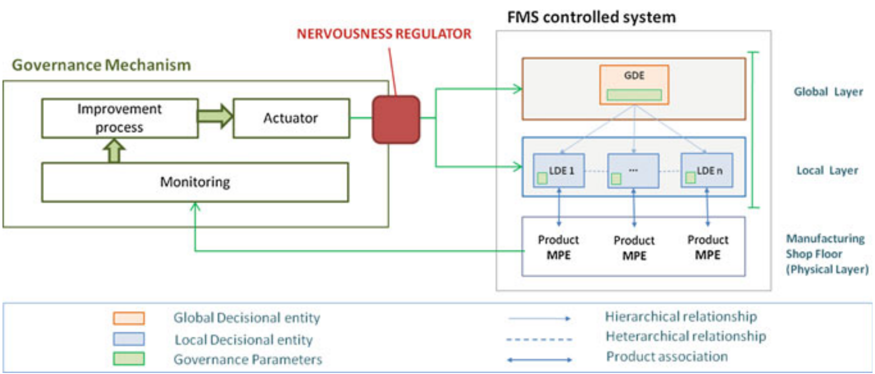



**Fig. 2** D-HCA of a FMS with a nervousness regulator

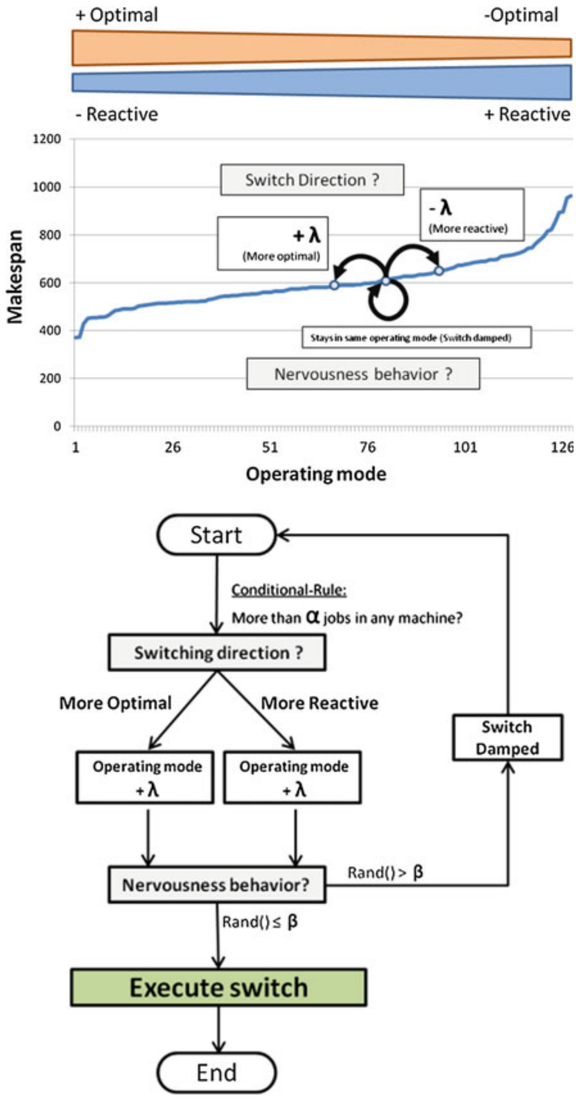
mode vector. It monitors the performance of the controlled FMS, continues with the improvement process for enhancing the system performance and triggers a change in the system's functioning by acting upon the operating mode vector (Fig. 2). Considering that the nervousness behaviour derived from the switching of the control system is monitored, the switching is triggered periodically (every 20 time-units) according to a condition-rule applied to the system. For measuring the performance of operating modes, the expected makespan without switching (*static*) was simulated for each possible operating mode vector. The result was sorted in a numbered list and plotted to characterize the operating modes (Fig. 3 top). The list contains 128 operating modes derived from the combination of the governance parameters of all LDE (*jobs to be produced*). In this model, it is assumed that this characterization of operating mode does not change through the execution and the results are considered a preliminary possible control solution. Finally, the direction of the switching towards an operating mode is decided by a condition-rule according to the intentions received from the resources. That is, if a certain resource has more than $\boldsymbol{\alpha}$ (Alpha) jobs to be produced at the switching time, the operating mode changes to a more reactive one (higher in the numbered list) with a step of $\lambda$ (Lambda) in the sorted list of operating modes. Otherwise, if all resources have less than four jobs intentions to be produced, the operating mode switches to better alternatives (lower in the numbered list).

**Nervousness regulator**: This entity is responsible for filtering the intentions of the governance mechanism to dampen the switching evolution. For the definition of nervousness indicator (NI) and Nervousness threshold (NT), the module proposed by Hadeli et al. [3] was used. This module employs a probabilistic mechanism each time the system is willing to change. As it is not evaluating the state of the system but dampening the system evolution, this approach is enclosed in the nervousness crisis prevention in the defined framework. The NI defined is a random value between 0 and 1, and the NT is fixed to $\boldsymbol{\beta}$ (beta). If NI is higher than NT the system holds the switch. Otherwise, the switching process is performed. The flow diagram of the nervousness linked to the switching mechanism is illustrated in Fig. 3 bottom.

## 5 Experimental Study and Results

This section presents the experiments performed in the manufacturing cell of the AIP PRIMECA lab. of the UVHC. The main goal of this experiment is to compare the behaviour of a D-HCA with and without a nervousness regulator; we wanted to prove that the nervousness mechanism damps the switching process and avoids thus a nervous behaviour. For the implementation, the proposed D-HCA with nervousness regulator is programmed in the NetLogo agent-based software [17]. The data-set used for the case study is the scenario A0 from the Benchmark [14].

**Fig. 3** D-HCA of a FMS with a nervousness regulator




For the setup of the D-HCA, the governance parameters of the decisional entities are initially fixed. The GDE presents a coercive role and the LDE is fixed with the values of the 80th operating mode. As initial values for the experiments, the conditional-rule $\boldsymbol{\alpha}$ is 4, the switching step $\boldsymbol{\lambda}$ is 2 and the nervousness threshold $\boldsymbol{\beta}$ is 0.9. When execution starts, the GDE communicates a coercive optimal plan to the LDE for the order release sequence. The emulation of the production system starts execution with this optimal plan and the initial operating mode. In the experiments, while part A considers the proposed D-HCA without the nervousness regulator, part B includes the regulator. Considering that the nervousness regulator is a probabilistic mechanism, it is executed 30 times for each part of the experiment. Finally, an analysis of variance (ANOVA) procedure is conducted to compare the differences between the results of part A and part B.

As a first result, the experiments showed that there are statistically significant differences between part A and B as determined by one-way ANOVA ($F(1,58) = 4.0068$, $p = 0.05$). In this respect, part B performs better in the production execution. In fact, even though this result does not demonstrate that constant switching can generate a nervousness state, the results show that the nervousness mechanism damps the switching. We believe that the results are essentially by two reasons. The first reason is that, due the rapid evolution of the system, damping the switching is imposing the system to stay in the same operating mode to take advantage of the benefits inherent to the configuration. Thus, the jobs are able to apply certain intentions settled by the operating mode of current execution. The second reason is that, when the nervousness regulator is activated, the jobs enter a stabilization period in which the regulator contributes avoiding the changes of intentions caused by the switching. Even though it was not confirmed in this experiment, the changes of intentions should diminish as a consequence of the stabilization period. These experiments confirm that the switching between different operating modes in a D-HCA achieves a better performance than a fully static configuration. In Fig. 4, while in a static operating the proposed architecture has 607 time-units as makespan, the switching for part A and B presents a mean of 509.40 and 473.76, respectively. In conclusion, from the experiments conducted, the nervousness regulator searches a convergence in the dynamic process in order to stabilize the trade-off between evolution and nervousness. However, these results raise the further need to balance between the switching and the nervousness behaviour mechanisms.

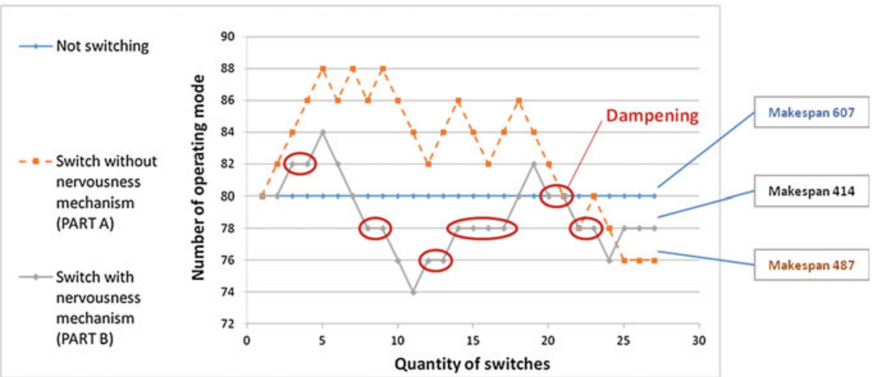



**Fig. 4** Examples of the evolution of switching during execution

## 6 Conclusions

A framework for a nervousness regulator in D-HCA was proposed. The framework defines the prevention, assessment, handling and recovery phases as possible locations to drive the nervousness behaviour present in a dynamic system. An instantiation of the nervousness regulator included in the D-HCA of a manufacturing was tested in an experiment of assembly. Results show that the nervousness regulator is needed to defuse the consequences of nervousness behaviour. The research perspective derived from this paper is to explore different models handling the nervousness and conceive an integral nervousness regulator that controls the nervousness in the four defined phases. Finally, a balance between switching frequency and nervousness behaviour need to be addressed.

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