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System Reliability Aware Model Predictive Control Framework

Jean C. Salazar[a,*], Philippe Weber[b], Fatiha Nejjari[a], Ramon Sarrate[a], Didier Theilliol[b]

[a] *Universitat Politècnica de Catalunya, Research Center for Supervision, Safety and Automatic Control (CS2AC), 10 Rambla Sant Nebridi, Terrassa, Spain*

[b] *Université de Lorraine, Centre de Recherche en Automatique de Nancy (CRAN), FST - B.P. 70239 54506 Vandoeuvre-lès-Nancy, France*

Abstract

This work presents a Model Predictive Control (MPC) framework taking into account the usage of the actuators to preserve system reliability while maximizing control performance. Two approaches are proposed to preserve system reliability: a global approach that integrates in the control algorithm a representation of system reliability, and a local approach that integrates a representation of component reliability. The trade-off between the system reliability and the control performance should be taken into account. A methodology for MPC tuning is proposed to handle this trade-off. System and component reliability are computed based on Dynamic Bayesian Network. The effectiveness and benefits of the proposed control framework are discussed through its application to an over-actuated system.

Keywords: Reliability, Dynamic Bayesian Networks, Model Predictive Control, Reliability Importance Measures

1. Introduction

The degradation of physical components in engineering systems is generally inevitable. In particular, the degradation of actuators in a closed-loop control system can lead to poor performance and sometimes in a loss of controllability. Therefore, actuator health is of great importance for the safety and reliability of the controlled system. Thus, to avoid failures it is important to enhance system safety by taking into consideration the reliability of components in the controller design [12].

If the design objective is still to maintain the original system performance, this may force the remaining actuators to work beyond their normal duty to compensate the handicaps caused by the fault. Therefore, the trade-off between achievable performance and available actuator capability should be carefully considered in all control designs.

Considerable research has been carried out in order to enhance the system reliability from the manufacturing and system structure point of view. Recently, system reliability has been taken into account in the system control process through a Prognosis and Health Management (PHM) framework. Mainly because reliability is as a measure of how long the system will perform its function correctly [7] and can be used to predict future failures in the system given the state of its components.

In some cases the control effort can be redistributed among the available actuators to relieve the work load and the stress factors on assets with worst conditions avoiding in this manner their deterioration. For this purpose, an appropriate policy should be developed to redistribute the control effort until maintenance actions can be taken. In this work, the actuator and system reliability are integrated in the control design and used as a policy which serves to redistribute the control effort among the actuators [23, 24].

This paper presents a method to manage the system reliability while performing the control of the system within a framework based on Model Predictive Control (MPC). For this purpose, the paper presents two approaches, the local approach, based on the components reliability and the global approach focused on the system reliability. As a result, a trade-off between system reliability and control performance arises.

The growing importance of maintenance has generated an increasing interest in the development and implementation of optimal maintenance strategies for improving system reliability, preventing the occurrence of system failures, and reducing maintenance costs of deteriorating systems [9].

MPC is an efficient technique to manage this kind of objectives. It allows the incorporation of several criteria in the optimization problem. By instance, in [8] the authors present an application of MPC to a Drinking Water Network (DWN) which includes in the optimization problem several criteria such as a criteria for economic cost, level of service and level of components degradation.

In [21] and [22], the MPC formulation includes the actuator usage as constraints, whose objective is to maintain the accumulated usage under a safety level at the end of the mission.

Reliability can be modelled as an exponential function [6, 33], as a Weibull function [2, 11] or a Gamma function

*Corresponding author
Email address: jean.salazar@upc.edu (Jean C. Salazar)