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STUDY ON SENSIBILITY OF INMEDIACY AND STABILITY WITH CHANGING PREDICTION HORIZON IN DMC CONTROL

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Abstract- In this work authors have carried out a study on the sensibility and stability shown by a concrete algorithm named Dynamic Matrix Control (DMC) that belongs to a wide family of Model Predictive Controllers (MPC). That study has used three indexes, i.e., t_{a5}, t_{r100} and t_p, and a total of 840 different experiments have been completed with different combinations of several parameters, being the prediction horizon the most important in the experimental setup. The result of this study is that the t_{a5} and t_p indexes are influenced by the prediction horizon p, but the t_{r100} index does not show that behavior.

Keywords: Model Predictive Control, Dynamic Matrix Control, Prediction Horizon, Objective Function.

I. INTRODUCTION

Model Predictive Control (MPC) is a generic control technique instantiated by means of a wide set of advanced control algorithms devoted to deal with complex systems. Different instantiations of this type of advanced controllers have been used and compared with Proportional Integrative Derivative (PID) controllers [4, 13], showing a good performance. We can found many applications in the literature, such as energy management [1], signal processing applications [9], multi-robot systems implementation [5, 6] and motor control [10], among others. They have shown their suitability for being implemented by means of neural networks [7], taking advance of their benefits. One of the most used of these algorithms is the Dynamic Matrix Control (DMC) algorithm. The main objective of this paper is to analyze the sensitivity of the objective function (and their components) of the DMC controllers under the effect of different prediction horizon values because we have neither studied nor found in the literature any study about the influence of the control horizon p on that objective function.

Table 1. Description of the response indexes

Index	Description
t_{a5}	Time elapsed between the rising edge of the reference step w and the stabilization of the output of the system in the neighborhood of 5% of the reference value w
t_{r100}	Time elapsed between the rising edge of the reference step w and the output of the system when it reaches the first time the reference value w
t_p	Peak time, i.e., the time elapsed between the step takes place until the overshoot occurs.

The paper is structured as follows. In the second section, we give a brief background and references about MPC and DMC. The third section introduces the immediacy and stability index that are used in this work. In the fourth section, we describe briefly the experimental design that we have carried out. The fifth, sixth and seventh sections discuss the results obtained on the analyzed indexes. Finally, the last section provides the conclusions of the paper.

II. BACKGROUND

This section gives a brief background and recalls some basic concepts and references of the literature where a good background on Model Predictive Control (MPC) and Dynamic Matrix Control (DMC) can be found.

Model Predictive Control (MPC) is an advanced control technique used to control systems that do not show a good behavior using classic control schemas (e.g. Proportional-Integrative-Derivative PID controllers). MPC controllers work like the human brain in the sense that instead of using the past error between the output of the system and the desired value, they control the system predicting the value of the output in a short time, in such a way the system output is as closer as possible to its desired value for these moments. MPC involves a set of techniques that share several characteristics, and the designer has liberty to choose them. So, there are several types of predictive controllers.

The first one of these common characteristics is that there is a plant model, and it can be used a step response model, an impulse step response model, a transfer function, etc. It is used to predict the system output from the actual moment until p samples. The second one is the existence of an objective function that the controller has to optimize, while the last one is that there is a control law to minimize the objective function. Predictive controllers follow a sequence of steps: each sampling time, through the system model, the controller calculates the system output from now until p sampling times (prediction horizon), which depends on the future control signals that the controller will generate. A set of m control signals (control horizon) is calculated optimizing the objective function to be used along m sampling times. In each sampling time only the first of the set of m control signals is used, and at the next sampling time, all the process is executed again.

For a deep insight about MPC and DMC see [2, 3, 8, 11 and 12].

III. INMEDIACY AND STABILITY INDEXES

In this section we describe the three indexes which have been monitored along all the experimentation phase with different values of the p parameter. The first one is the t_{a5} index is also monitored and used to measure the stability of the system in the unorthodox sense of the time needed to the stabilization of the output of the system in the neighborhood of 5% of the reference value w. Obviously, the smaller the t_{a5} index, the more stable will be the controlled response of the system. On the other hand, the t_{r100} index tries to capture the immediacy of the response of the system in the sense of measuring the first time that the output of the system reaches the 100% of the reference value w. The smaller the t_{r100} index, the more immediate will be the controlled response of the system. Finally, the t_p index measures the time elapsed between the step takes place until the overshoot occurs. The description of the three indexes can be found in Table 1, while the graphical representation is shown in Figure 1.

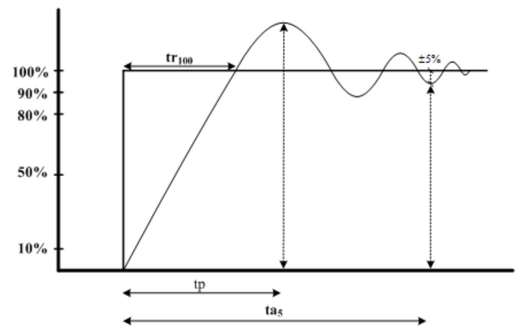

Figure 1. Graphical representation of the response indexes

IV. EXPERIMENTAL SETUP

In this section the experimental design that has been used to study the effect of the prediction horizon p in the immediacy and stability indexes described in the previous section is described. A wide range of different values of the parameters p, m and λ have been combined. The values that have been used for the prediction horizon p (the parameter for which the analysis is being carried out) are $\{p \in [2, 5, 8, 11, 14, 17, 20]\}$. The range of values for the control horizon m is contained in the set $\{m \in N^+ \wedge m \in [1, 20]\}$. Finally, the values of the λ parameter are $\{\lambda \in [10^{-3}, 10^{-2}, 10^{-1}, 1, 10^{1}, 10^{2}]\}$. Carrying out the Cartesian product of these ranges, the result is an experimental design composed of 840 simulations. With regard to the system that has been used to carry out the experimentation, the main part of the argumentation on its utilization has been intentionally omitted due to space issues. Its detailed description, the determination of the working point can be found in [4]. Its dynamics is described through Equation (1) and its response though Figure 2, while controlled by means of a discrete PID controller tuned using the Ziegler-Nichols method. There we can see that its response is clearly unstable when the system is excited by a unitary step.

$$H(z) = \frac{1}{z - 0.5} \tag{1}$$

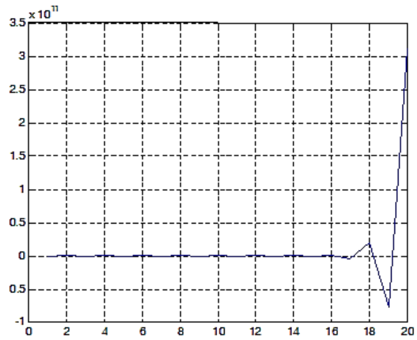

Figure 2. Unstable response of the closed loop system while controlled by a discrete PID controller (excited by a unitary step)

V. SENSITIVITY OF t_{a5} INDEX

In this subsection we describe the results that we have reached on the sensibility of the t_{a5} stability index under the controlling action of DMC controllers with different prediction horizon p values. A number of figures have been obtained varying the p parameter, as can be seen through Figures 3-7. In this case a very clear influence of the p parameter can be observed because the larger is p, the smaller is t_{a5}. For all values of the p parameter, there are one or more combinations of the m and λ parameters that allows to the t_{a5} index to go from close to 0 s to more than 10^2 s.

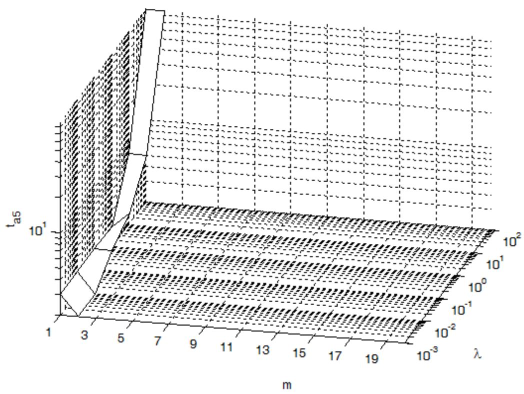

Figure 3. t_{a5} with $p = 2$

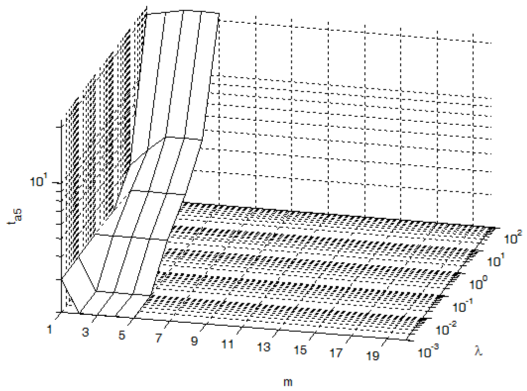

Figure 4. t_{a5} with p = 5

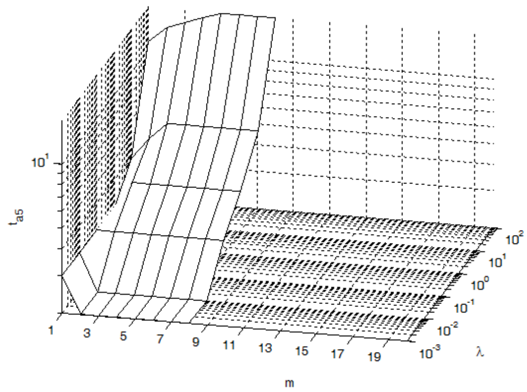

Figure 5. t_{a5} with p = 8

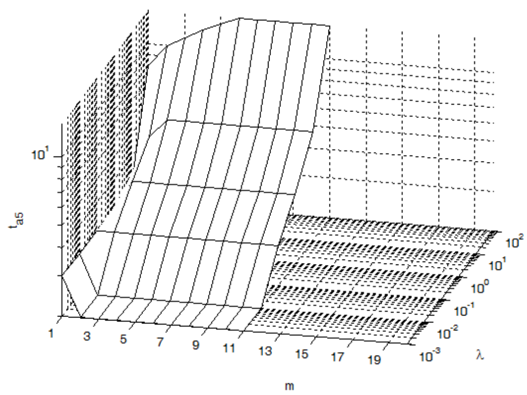

Figure 6. t_{a5} with p = 11

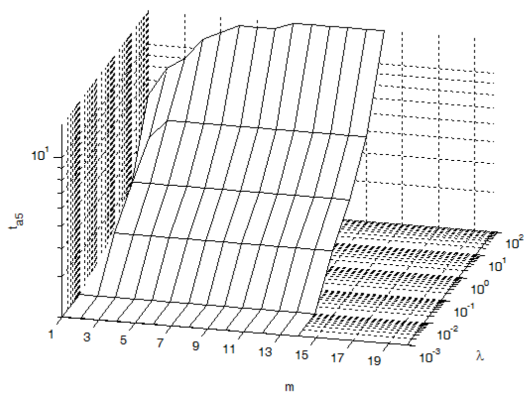

Figure 7. t_{a5} with p = 14

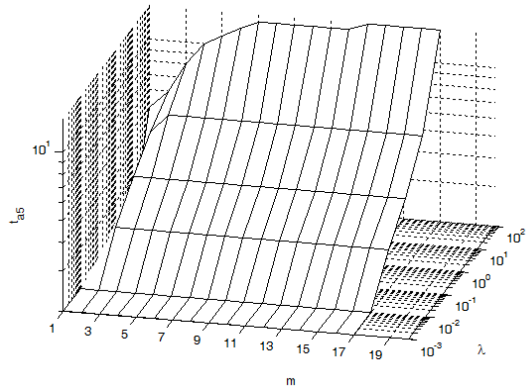

Figure 8. t_{a5} with p = 17

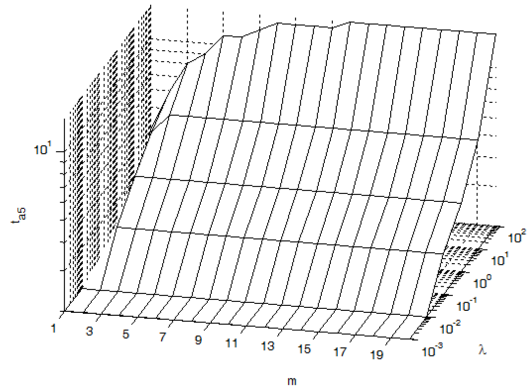

Figure 9. t_{a5} with p = 20

VI. SENSITIVITY OF t_{r100} INDEX

In this subsection we describe the results that have been found on the sensibility of the t_{r100} immediacy index under the controlling action of DMC controllers with different prediction horizon p values. A number of figures have been obtained varying the p parameter, as can be seen through Figures 10-16.

After analyzing those figures, we can conclude that in general, the shape of the immediacy index t_{r100} is maintained for a concrete combination of values of the m and λ parameters, with different values of the p parameter. The range of values goes from 10^0 s (with small values of the λ parameter, independently of the value of the m parameter) to more than 10^3 s, indicating these very large values that the simulation has finished before the output of the system has reached the reference w, i.e., there is not overshot.

For a given values of the m and λ parameters, the value of the t_{r100} index increases and becomes slightly worst as the prediction horizon p increases. This is because the predictions of the future output of the controlled system are less accurate when there is more distant in time. For all values of the p parameter, with m=1 a worst result than with $m\geq2$ is obtained.

In general, the shape of the curves is similar to those of the t_{a5} immediacy index because if the output of the controlled system is slow to rise and approach to the reference signal *w*, obviously it will also be slow to establish in its neighborhood. Due to this reason the values of t_{a5} are larger than of t_{r100} in general for the same combination of parameters.

However there are some combinations for which this does not happen: it is because in these cases there is a large damping and the output signal does not reach the reference *w*, but its gets close to it falling into its neighborhood. Finally, we have realized that the λ parameter is determinant because except with very large values of λ, value of the t_{r100} index remains under 10 s.

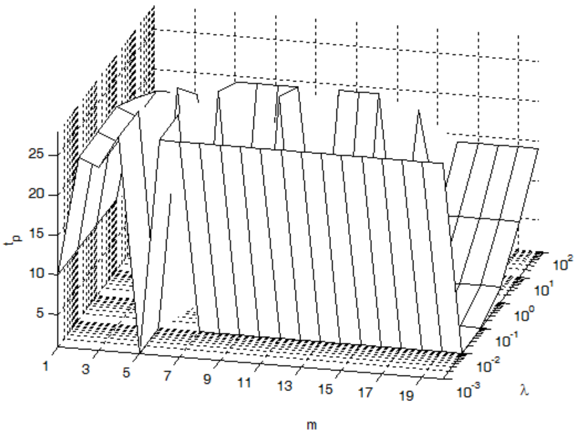

Figure 10. t_{r100} with p = 2

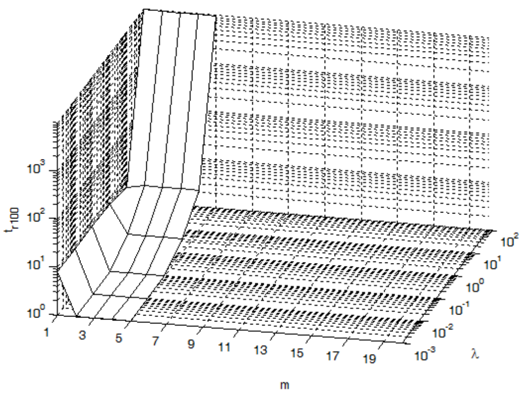

Figure 11. t_{r100} with p = 5

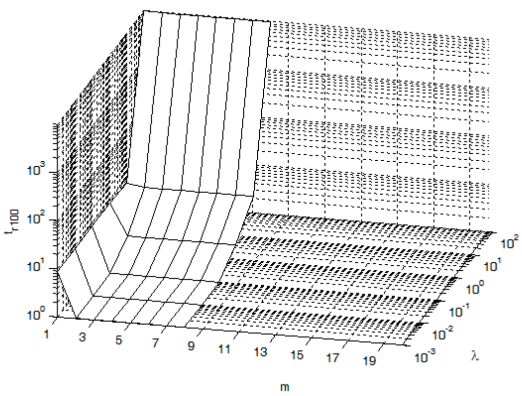

Figure 12. t_{r100} with p = 8

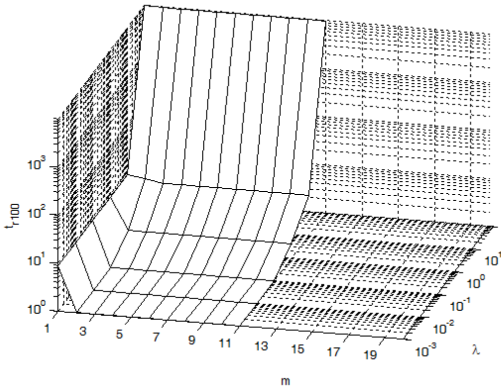

Figure 13. t_{r100} with p = 11

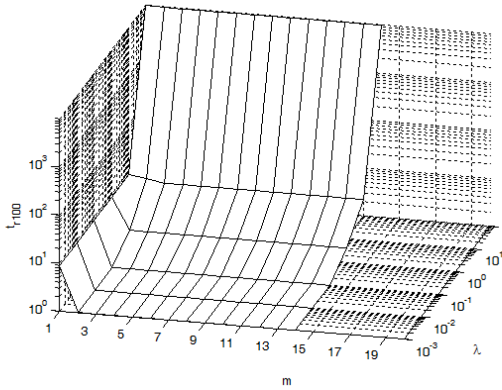

Figure 14. t_{r100} with p = 14

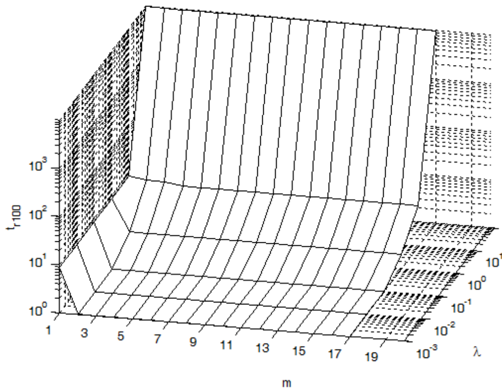

Figure 15. t_{r100} with p = 17

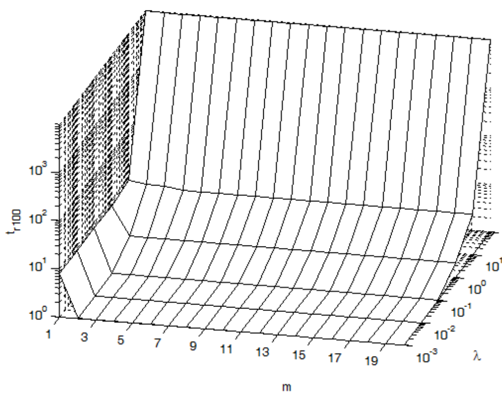

Figure 16. t_{r100} with p = 20

VII. SENSITIVITY OF t_p INDEX

In this subsection we summarize the effect on the t_p performance index values, taking into consideration Figures 17-23, reaching the following conclusions. There is not a clear influence of the prediction horizon parameter on the moment when the overshoot takes place (the t_p performance index), because its value does not experiment large changes due to the p parameter value, but rather due to the λ parameter. Its value is usually around 20 or 30 sample times, and the peak usually occurs at the end of the pulse, just before the falling edge. The main conclusion is that it takes place on the range of 20-30 seconds after the unitary step signal with the most of the configurations. Only when p=1, in some configurations it takes place before of 5 seconds after the reference signal.

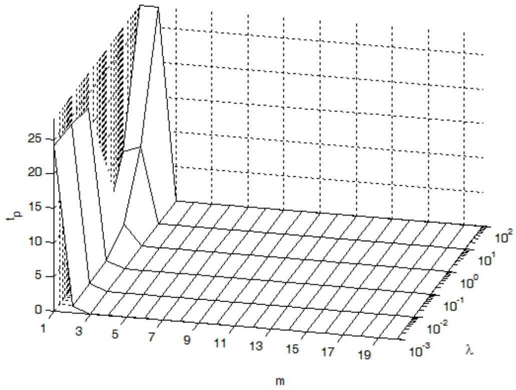

Figure 17. t_p with p = 2

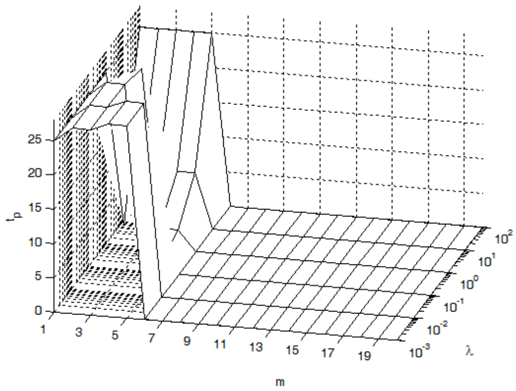

Figure 18. t_p with p = 5

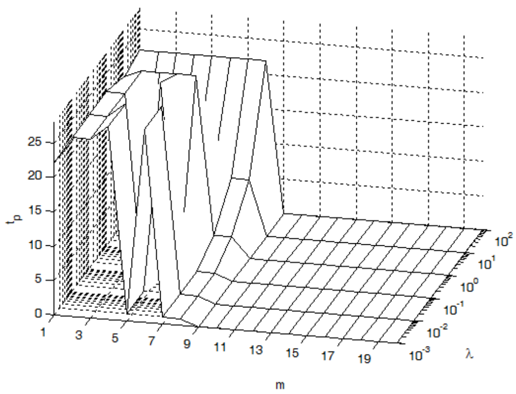

Figure 19. t_p with p = 8

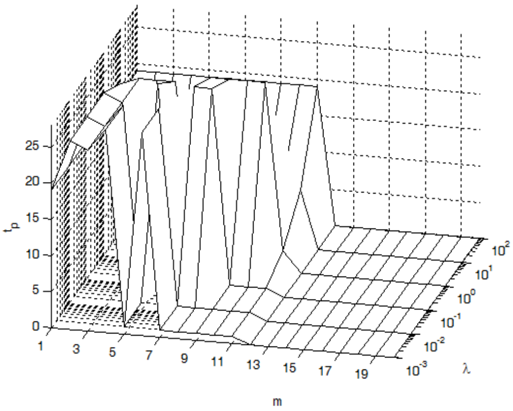

Figure 20. t_p with p = 11

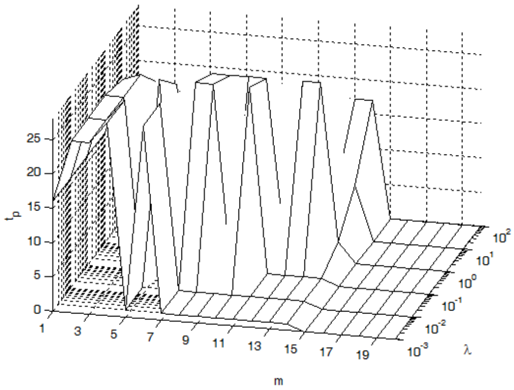

Figure 21. t_p with p = 14

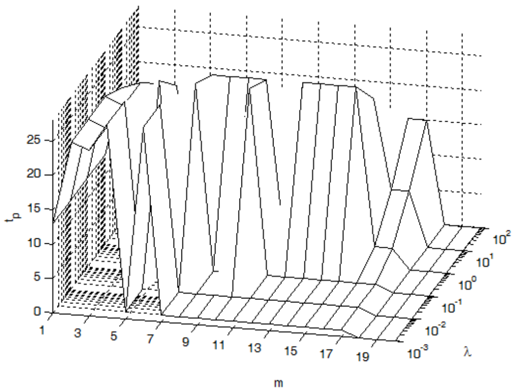

Figure 22. t_p with p = 17

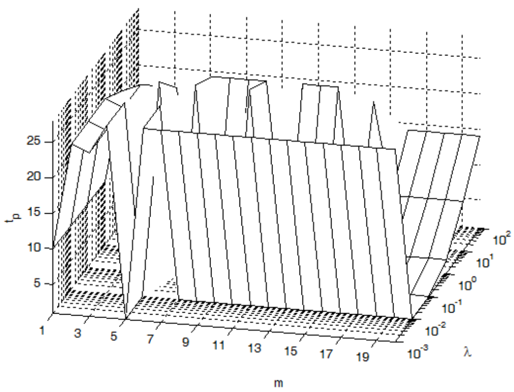

Figure 23. t_p with p = 20

VIII. CONCLUSIONS

The paper started with a first section, which describes the scope and applications of Model Predictive Control and Dynamic Matrix Control, at the same time that the objective of the paper is stated. A brief background is given in the second section, while in the third section the used indexes are described. Later we have described the experimental design that involves 840 experiments. The results discussed in the fifth, sixth and seventh sections show that the prediction horizon p is significant regarding the t_{a5} and t_p indexes, however it is does not exert a very important effect on the index t_{r100}.

NOMENCLATURES

p: The prediction horizon
m: The control horizon
λ: The parameter of the DMC controller related to its embodiment
t: The time instant
w : The reference signal
t_{r100}: The immediacy index
t_{a5}: The stability index

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REFERENCES

[1] E. Bijami, J. Askari Marnani, S. Hosseinnia, "Power System Stabilization Using Model Predictive Control Based on Imperialist Competitive Algorithm", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 9, Vol. 3, No. 4, pp. 45-51, December 2011.
[2] E.F. Camacho, C. Bordons, "Model Predictive Control", Springer-Verlag, London, United Kingdom, 2004.
[3] E.F. Camacho, C. Bordons, "Model Predictive Control in the Process Industry", Springer-Verlag, London, United Kingdom, 1995.
[4] J.M. Lopez Guede, B. Fernadez Gauna, M. Grana, F. Oterino, J.M. Larranaga, "Effect of the Lambda Parameter in Dynamic Matrix Controllers Performance", Publishing Services LLC, Journal of Computer and Information Technology, Vol. 2, No. 2, pp. 81-88, 2012.
[5] J.M. Lopez Guede, M. Grana, E. Zulueta, O. Barambones, "Economical Implementation of Control Loops for Multi-Robot Systems", 15th International Conference on Neural Information Processing (ICONIP 2008), pp. 1053-1059, Auckland, New Zealand, 25-28 November 2008.
[6] J.M. Lopez Guede, E. Zulueta, B. Fernandez, M. Grana, "Multi-Robot Systems Control Implementation", Robot Learning, pp. 137-150, Rijeka, Croatia, 2010.
[7] J.M. Lopez Guede, E. Zulueta, M. Grana, A. D'Anjou, "Neuronal Implementation of Predictive Controllers", 5th International Conference on Hybrid Artificial Intelligence Systems (HAIS 2010), pp. 312-319, San Sebastian, Spain, 23-25 June 2010.
[8] J.M. Maciejowski, "Predictive Control with Constraints", Prentice Hall, London, United Kingdom, 2002.
[9] E. Mahmoodi, M.M. Farsangi, "Design of Stabilizing Signals using Model Predictive Control", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 2, Vol. 2, No. 1, pp. 1-4, March 2010.
[10] J.L. McKinstry, G.M. Edelman, J.L. Krichmar, "A Cerebellar Model for Predictive Motor Control Tested in a Brain-Based Device", Proceedings of the National Academy of Sciences of The United States of America, Vol. 103, No. 9, pp. 3387-3392, USA, 2006.
[11] R. Soeterboek, "Predictive Control, A Unified Approach", Prentice Hall, USA, 1992.
[12] H. Sunan, T. Kok, L. Tong, "Applied Predictive Control", Springer-Verlag, London, United Kingdom, 2002.
[13] M. Voicu, C. Lazar, F. Schonberger, O. Pastravanu, S. Ifrim, "Control Engineering Solution - A Practical Approach, Predictive Control" vs. "PID Control of Thermal Treatment Processes, Control Engineering Solution - a Practical Approach", pp. 163-174, The Institution of Electrical Engineers, London, United Kingdom, 1997.

BIOGRAPHIES

Jose Manuel Lopez Guede was born in Eibar, Spain, 1976. He received the M.Sc. degree in 1999 and the Ph.D. degree in 2012, both in Computer Sciences from University of the Basque Country, San Sebastian, Spain. Since 2002 he is working at the same university. His current position is Lecturer at Systems Engineering and Automatic Control Department at the University College of Engineering of Vitoria Gasteiz, Spain.

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Ismael Soto is an Electrical Engineer, Master in Electronics and Ph.D. in Telecommunications. He Currently works in the Department of Electrical Engineering, University of Santiago de Chile, as full Professor. He is also responsible for laboratory research GETIC, from which has contributed to the generation of engineers and PhD. In the last years the emphasis has been in the Digital Signal Processing, prioritizing transmission applications, the modelling for the optimization of coding and cryptography to be used on wireless communications and nanotechnology.

Aitor Moreno received the Computer Engineering degree in 1995 at the University of Deusto and the Master's Degree in Advanced Artificial Intelligence in 2008. Since September 2008, he manages projects related to the implementation of control systems based on neural networks, genetic algorithms, fuzzy logic systems and expert systems to the analysis of large volumes of information. He has published several scientific papers and informative concerning the application of Artificial Intelligence in real situations, and has participated in national and other events as speaker.