International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2014	Issue 19	Volume 6	Number 2	Pages 76-81

TIME INDEXES SENSITIVITY TO CONTROL HORIZON IN DMC CONTROL

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Abstract- In this work authors study the sensibility of two time response performance indexes and one stability index to the control horizon parameter in a concrete Model Predictive Control (MPC) technique named Dynamic Matrix Control (DMC). During the experimentation phase, 840 different configurations have been tested. In order to provide higher insight, to carry out the experiments we have chosen a system that has shown to be unstable when it has been tried to control with a PID tuned with a heuristic method, showing that the value of the time response and stability performance indexes vary with a concrete pattern.

Keywords: Time Response Index, Control Horizon, Model Predictive Control, Dynamic Matrix Control.

I. INTRODUCTION

Model Predictive Control (MPC) is control paradigm composed of a wide set of advanced control techniques devoted to deal with complex systems. This type of advanced controllers has been used and compared with classic PID controllers [4, 13], showing a good performance. In the literature they have been used for a wide variety of applications, such as energy management [1], signal processing applications [9], multi-robot systems implementation [5, 6] and motor control [10], among others. Besides, they have shown their suitability for being implemented by means of neural networks [7], taking advance of their benefits.

One of the most popular of these techniques is the Dynamic Matrix Control (DMC) algorithm, and the main objective of this paper is to analyze the sensitivity of three time response performance indexes under the effect of different control horizon values. Because we have neither studied nor found in the literature any study about the influence of the control horizon *m* on these time response performance indexes. In the opinion of authors, this circumstance arises because it is usually supposed a fixed implementation of the predictive controller, which is defined by a concrete set of the *p*, *m* and λ parameters.

Besides, one of these indexes can be considered as a stability indicator, as we may see later when they will be discussed deeply. The paper is structured as follows. In the second section, we recall some classic references about MPC and DMC, where fundamental explanations about MPC and DMC will be found, and the importance and the role of the *m* parameter in such control scheme will be exposed. A reference to a previous work where the controlled system and its working point are detailed.

In the third section, we describe briefly and represent graphically the time response performance indexes that we have used to describe the performance and the stability of the DMC controllers. The fourth section gives the experimental setup that we have carried out. The fifth section exposes the results obtained on the t_p index, the sixth on the t_s index and the seventh on the t_{a2} index, explaining the effects of the changing parameter on each index independently. Finally, the last section provides our conclusions.

II. BACKGROUND AND PREVIOUS RELATED WORKS

In this section, we are going to give a brief background and to recall some classic references of the literature where a good background on MPC and DMC can be found. MPC is an advanced control technique used to deal with systems that are not controllable using classic control schemas, e.g. Proportional-Integral-Derivative (PID) controllers. In fact, it is not a concrete technique, it is a set of algorithms with several common characteristics, there is a world model that is used to predict the system output from the actual instant until *p* samples.

An objective function that must be minimized and a control law $\Delta u(t)$, which minimizes that objective, function by *m* control actions, and a λ parameter that defines the embodiment of the controller. For a deep insight about MPC and DMC see [2, 3, 8, 11, 12]. Finally, with regard to the system that has been used to carry out the experiments, 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]. At this point, we only describe its dynamics through Equation (1) and its response though Figure 1 while controlled by means of a discrete PID controller tuned by means of the Ziegler-Nichols method. There we can see that its response is clearly unstable.

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

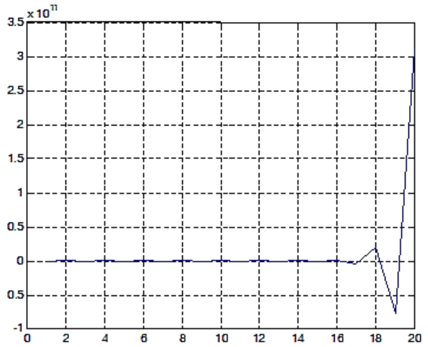

Figure 1. Unstable response of the closed loop system while controlled by a discrete PID controller tuned by means of the Ziegler-Nichols method

III. TIME AND STABILITY RESPONSE INDEXES

In this section, we describe the three-time response indexes that we have monitored during experimentation carried out, paying attention to the time response of the output of the controller relative to the reference signal. The three time response indexes are described in Table 1, while a graphical representation is shown in Figure 2. The first two indexes are relatives to the speed of reaching the level of the reference signal, while the last is devoted to measure the time needed to obtain a stabilized signal with an error in the neighborhood of 2% of the reference signal, so it can be understood as a stability index.

Table 1. Description of the time response indexes

Index	Description
t_p	Peak time, i.e., the time elapsed between the step takes place until the overshoot occurs
t_s	Time elapsed between the output goes from 10% to 90% of the reference value
t_{a2}	Time elapsed between the rising edge of the reference and the stabilization of the output in the neighborhood of 2% of the reference value

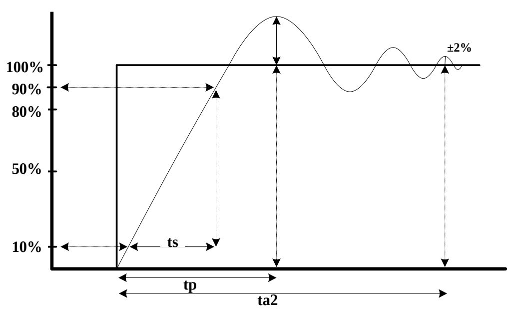

Figure 2. Graphical representation of the time performance indexes

IV. EXPERIMENTAL SETUP

As stated in the introduction section, the main objective of this work is the study of the time performance indexes sensitivity to the control horizon parameter *m*. To give deeper insight in this regard, we have designed a set of experiments that we describe in this section. A number of different values of the parameters *p*, *m* and λ have been taken. The values that have been involved for the control horizon *m* (the parameter for which the sensibility study is carried out) are $\{m \in [1, 3, 5, 7, 10, 15, 20]\}$. The value for the prediction horizon *p* is contained in the set $\{p \in N^+ \wedge p \in [1, 20]\}$. Finally, the values of the λ parameter are $\{\lambda \in [10^{-3}, 10^{-2}, 10^{-1}, 1, 10^{1}, 10^{2}]\}$. Making Cartesian product of these sets, the result is composed of 840 experiments.

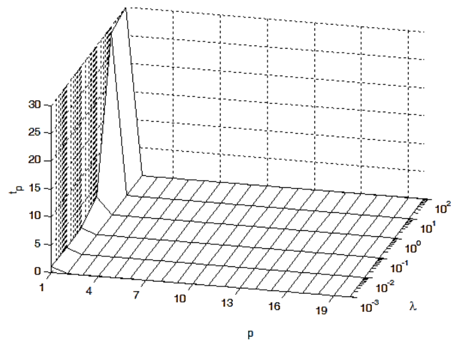

Figure 3. t_p with $m = 1$

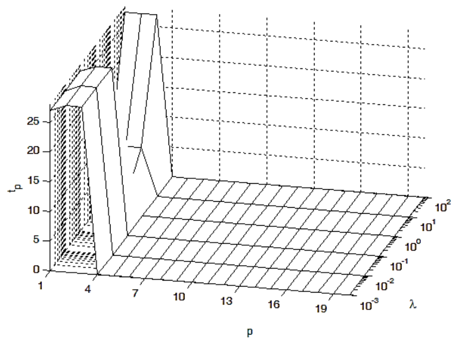

Figure 4. t_p with $m = 3$

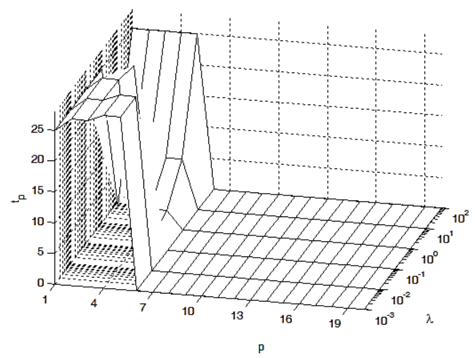

Figure 5. t_p with $m = 5$

V. SENSITIVITY OF t_p INDEX

In this subsection, we discuss the results that we have obtained on the sensibility of the t_p time performance index under the controlling action of DMC controllers with different control horizon *m* values. A number of figures have been obtained varying the m parameter, as can be seen through Figures 3-9. In Figure 3 we can see that there is a quite small value for the peak time t_p less than 5 s with m = 1 when small to medium range of values of the λ parameter are involved, resulting in a large value of 30 s for large values of that parameter. With larger values of m of 3, 5, 7, 10, 15 and 20 we can see in Figures 4 to 9 respectively that with increasing values of the control horizon m. The value of the t_p time performance index becomes larger independently of the prediction horizon parameter of the controller, because for the most part of them it is usual to see peak values of 25 s.

The only obvious pattern seems to be that with medium values of the embodiment parameter λ the peak time decreases significantly near to 5 s, otherwise with very low and very large values, it increases again. After this analysis and with regard to the peak time performance index, it is convenient to use a very moderate value of m, because in addition to make the calculus more complex with a larger vector $\Delta u(t)$ and matrix G, the resulting output does not reach better values of this index.

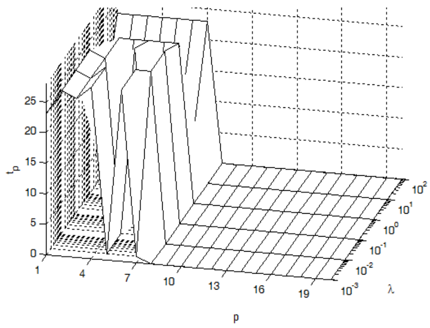

Figure 6. t_p with m = 7

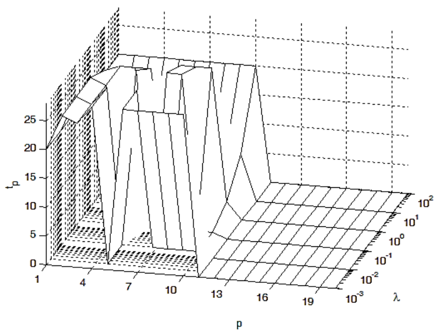

Figure 7. t_p with m = 10

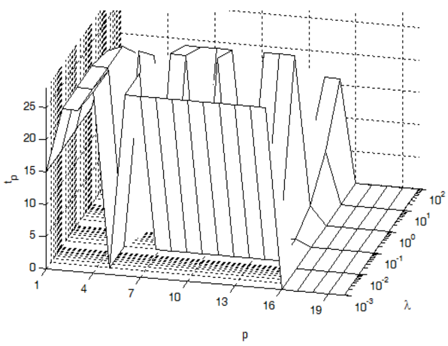

Figure 8. t_p with m = 15

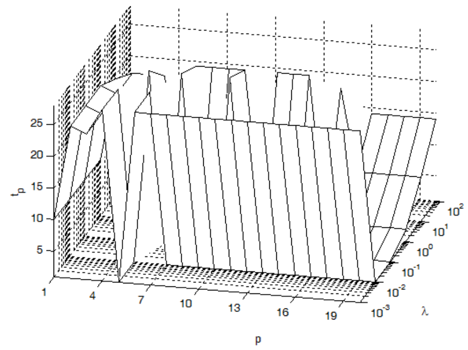

Figure 9. t_p with m = 20

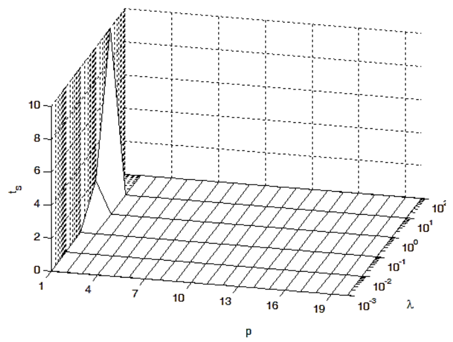

Figure 10. t_s with m = 1

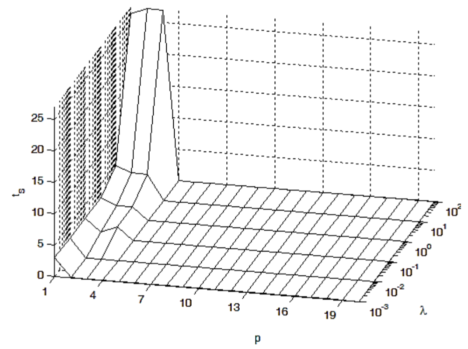

Figure 11. t_s with m = 3

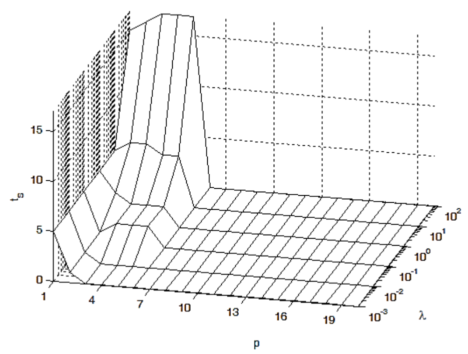

Figure 12. t_s with m = 5

VI. SENSITIVITY OF t_s INDEX

In this subsection we describe the results that we have reached on the sensibility of the t_s time performance index under the controlling action of DMC controllers with different control horizon m values. A number of figures have been obtained varying the m parameter, as can be seen through Figures 10 to 16.

After analyzing those figures, we can conclude that there is not a clear pattern regarding the t_s performance index in respect of the m parameter, because with the smallest value of m = 1 we obtain the best response (with a maximum of t_s = 10 s) of all the obtained results varying that parameter. With the next tested value, i.e., with m = 3, we obtain the worst value (a maximum of t_s = 25 s), while with the remaining values of m = 5, m = 7, m = 10, m = 15 and m = 20, the values of the time performance index falls to a maximum of t_s = 15 s.

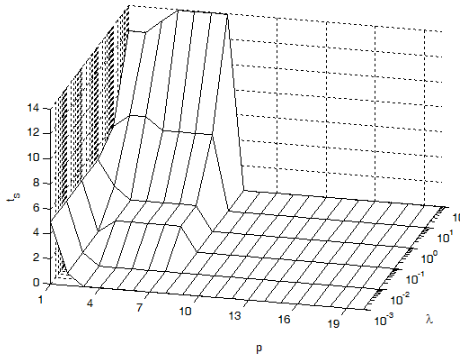

Figure 13. t_s with m = 7

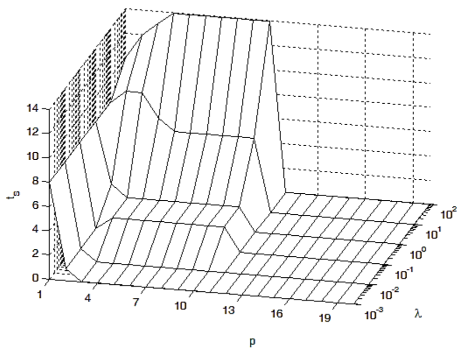

Figure 14. t_s with m = 10

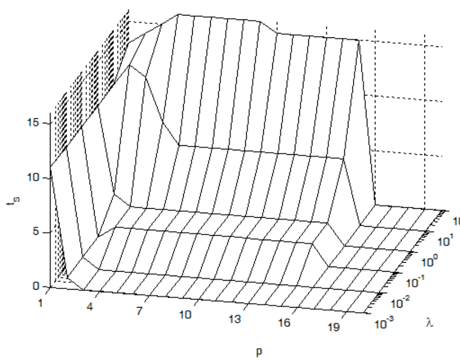

Figure 15. t_s with m = 15

The value of the prediction horizon p does not seem to be significant except to very low values (until p = 3), for which its contribution leads to poor results. However, the most significant parameter is the embodiment parameter λ because the best results ($t_s \approx 0$ s) are always obtained with its smallest value, and the worst always with its larger value.

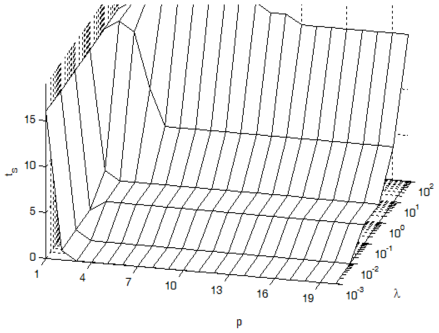

Figure 16. t_s with m = 20

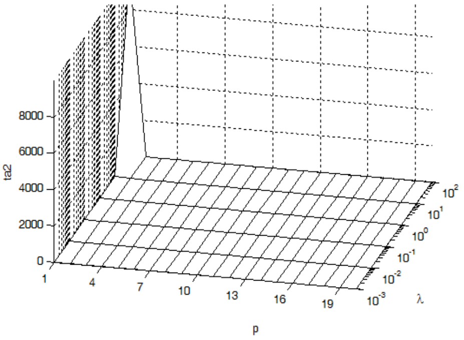

Figure 17. t_{a2} with m = 1

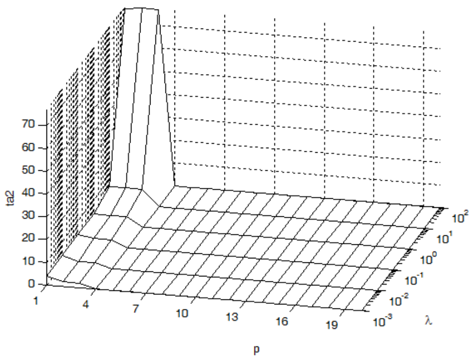

Figure 18. t_{a2} with m = 3

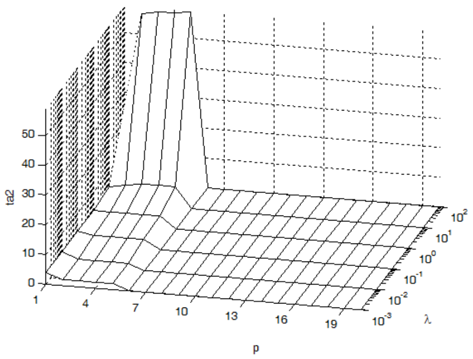

Figure 19. t_{a2} with m = 5

VII. SENSITIVITY OF t_{a2} INDEX

In this subsection we describe the results that we have reached on the sensibility of the t_{a2} stability performance index under the controlling action of DMC controllers with different control horizon m values. A number of figures have been obtained varying the m parameter, as can be seen through Figures 17-23.

In this paper, the t_{a2} index is used as a kind of stability index because it gives us an idea of how much time is needed to reach an output value in the neighborhood of the reference signal with a given precision. The first striking result is obtained in Figure 17 with $m = 1$: with high values of the embodiment parameter λ, a very high value of the t_{a2} index is reached. That circumstance means that the output of the controlled system never reaches a value inside a neighborhood of 2% of the reference signal. This poor response is not obtained with the remaining tested values of the m parameter.

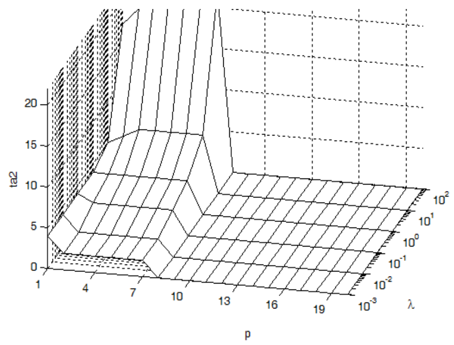

Figure 20. t_{a2} with $m = 7$

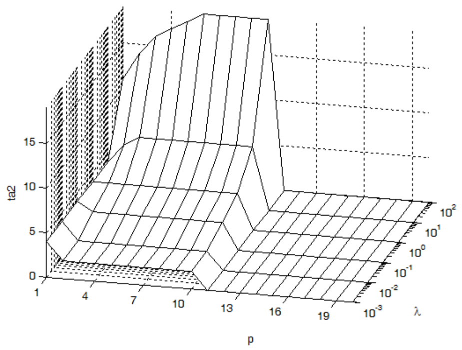

Figure 21. t_{a2} with $m = 10$

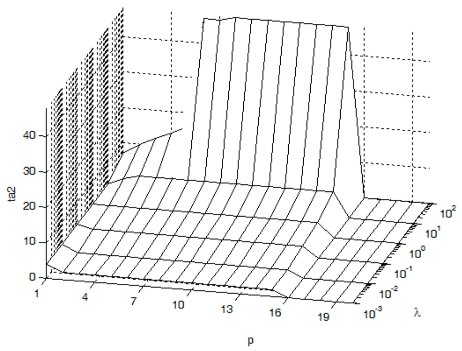

Figure 22. t_{a2} with $m = 15$

In general, we state that for all tested values of the m parameter the value of the embodiment parameter λ is relevant. As we can see in Figure 17-23 the value of the t_{a2} index is much larger with high values of that parameter while it is near zero under several circumstances, being one of them that λ is small, as in Figure 23. Another striking result is that with all tested values of $m > 3$ there is a significant reduction of the t_{a2} index with high values of the parameter λ (that is just when the response is worst) when the p parameter is small. Even with some values ($m = 5$, $m = 15$, and $m = 20$) falls abruptly from peak values to moderate ones.

The last remarkable result is that with a larger control horizon m, e.g. with $m = 20$ (Figure 23), the value of the t_{a2} index is very small for the most part of the combinations of the λ and p parameters. This means that even although only the first component of the m components available from the control vector is taken, a large control horizon helps to obtain a more accurate prediction values, and that helps to the overall process.

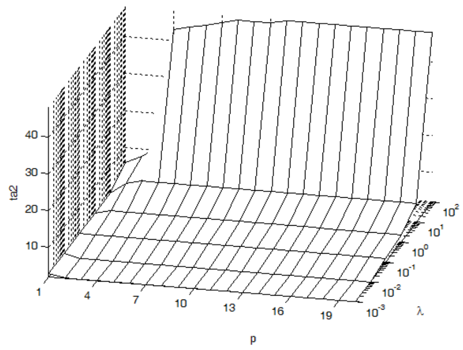

Figure 23. t_{a2} with $m = 20$

VIII. CONCLUSIONS

We have started this paper reviewing the scope and the application field of Model Predictive Control (MPC) and Dynamic Matrix Control (DMC) techniques in the first section, giving a short background and referencing some previous related works and relevant sources of information regarding this general and particular technique. We have motivated the study of the effect of the control horizon parameter m on time performance indexes and we have stated that as the objective of the paper. We have described the two time performance indexes that have been involved in this research and a stability response index.

Later we have described the experimental design that has been carried out, generating a total of 840 experiments. The fifth, sixth and seventh sections discuss the results that have been reached showing them through a number of figures, splitting the discussion based on each index. After analyzing the reached results our conclusion is that the control horizon parameter m is relevant regarding the time and stability performance indexes of the DMC controller, influenced in some way by the prediction horizon p and the embodiment parameter λ.

NOMENCLATURES

G: The dynamic matrix of the DMC controller
λ: The parameter of the DMC controller related to its embodiment.
m: The control horizon
t: The time instant
t_{a2}: The elapsed between the rising edge of the reference and the stabilization of the output in the neighborhood of 2% of the reference value (performance index)
t_p: The time elapsed between the step take place until the overshoot occurs (performance index)

t_s: The time elapsed between the output goes from 10% to 90% of the reference value (performance index)
p: The prediction horizon
$u(t)$: The whole input of the controlled system at time t
$\Delta u(t)$: The output of the DMC controller at time t

ACKNOWLEDGEMENTS

The research was supported by Grant 6719 of Teaching Innovation Projects 2013-15 of the Education Advisory Service, Vicerectorship for Teaching Quality and Innovation, Basque Country University (UPV/EHU), whose support is greatly acknowledged. The authors would like to thank the cooperative work developed by the students who kindly participated in the previously referred project using cooperative learning techniques, which was supervised by the authors.

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.

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