

Real Time Evolution (RTE) for on-line optimisation of continuous and semi-continuous chemical processes

by

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Barcelona, May 2003

A thesis submitted in partial fulfilment of the requirements for the degree of
Doctor of the Universitat Politècnica de Catalunya

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Ab imo pectore

to my family

*In questions of science, the authority of a thousand is not worth the humble reasoning of a
single individual
Galilei, Galileo (1564-1642)*

Summary

In general, process control is very effective when the desired operation point has been determined from prior analysis and the control system has sufficient time to respond to disturbances. While process control is required for regulating some process variables, the application of these methods may be not appropriate for all important variables. In some situations, the best operating conditions change because of the combined effect of internal and external disturbances, and a fixed control design may not respond properly to these changes. When certain conditions are met, on-line optimisation becomes a suitable choice for tracking the moving optimum.

In order to “pursue” that moving optimum, on-line optimisation solves periodically optimisation problems using data coming directly from the plant and a continuously updated model. The most common use of on-line optimisation corresponds to the continuous processes category. This is mainly owed to that steady state models are simpler and easier to develop and validate, besides that continuous processes have commonly high production rates, thus small relative improvements in the process efficiency originates significant economic earnings. Nevertheless, although the use of steady state models greatly simplifies the modelling task, it raises other issues associated with the validity of the steady state assumption.

Large-scale applications of on-line optimisation started to spread, however, even when several vendors offer products and services in the area, most of the application address advanced control issues while on-line optimisation is released to a second plane. Industry practitioners have reported that after four decades there has been a progressive improvement in the on-line optimisation methodology, but the same initial weakness or more generally speaking some common causes of poor performance still remain. These issues are directly related with the steady state detection (or disturbance frequency) and the optimisation itself.

The objectives of this thesis work are then directed to overcome at least partially the weak points of the current approach. The result is the proposal of an alternative strategy that takes fully advantage of the on-line measurements and looks for periodical improvement rather than a formal optimisation. It is shown how the proposed approach results very efficient and can be applied not only for set-point on-line optimisation but also for taking the on-line decision required in processes that presents decaying performance (aspect typically solved of-line via mathematical programming).

The thesis is structured as follows. The first chapter explains the main motivations and objectives of the work, while chapter 2 consists in a literature review that addresses, to some extension,

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the most significant issues around the on-line optimisation functionality. After that, chapter 3 and chapter 4 introduce two methodologies that use the proposed strategy for on-line optimisation, which is the main thesis contribution. The first one (in chapter 3) focuses in tracking fast moving optima, which is caused mainly by the combined effect of external and internal disturbances. On the other hand, a parallel methodology is explained in 4, conceived for processes that present decaying performance and that require discrete decision related to maintenance actions. Both chapters include a first part, rather theoretical, and a second part devoted to the validation over typical benchmarks. Then, chapter 5 describes the application of such methodologies over two existing industrial scenarios, in order to complement the results obtained using the benchmarks. After that, chapter 6 addresses two issues related to the implementation aspects: the influence of the adjustable parameters of the proposed procedure and the software architectures used. Finally, chapter 7 draws conclusions and main observations.

Resumen

En general, el control de procesos es muy eficiente cuando el punto de operación deseado ha sido determinado a priori y el sistema tiene capacidad suficiente para responder a las perturbaciones. Mientras el control de procesos es requerido a fin de regular algunas variables de proceso, la aplicación de tal técnica puede no ser apropiada para todas las variables significativas. En algunos casos, el punto óptimo de operación cambia debido al efecto combinado de perturbaciones internas y externas por lo que un sistema de control prefijado puede no responder adecuadamente a los cambios. Cuando ciertas condiciones son satisfechas, la optimización en-línea surge como una alternativa adecuada para ajustarse a ese óptimo cambiante.

A fin de “perseguir” este óptimo móvil, la optimización en-línea resuelve en forma periódica problemas de optimización, usando datos que vienen directamente de la planta y un modelo el cual es actualizado continuamente. La aplicación más frecuente de la optimización en-línea corresponde a la categoría de procesos continuos. Esto se debe principalmente a que los modelos de estado estacionario son más simples y fáciles de desarrollar y validar, además de que los procesos continuos tienen normalmente asociada elevada producción y por ende, pequeñas mejoras en la eficiencia del proceso se traducen en importantes ganancias. Sin embargo, aunque el uso de modelos al estado estacionario simplifica enormemente las tareas de modelización, hace emerger ciertos aspectos ligados a la validez de la hipótesis de un estado estacionario.

Comenzaron a surgir varias aplicaciones a gran escala de la optimización en-línea, pero, si bien varios vendedores ofrecen productos y servicios en este área, la mayoría de las aplicaciones industriales abordan problemas de control avanzado, dejando a la optimización en un segundo plano. Los industriales han reportado que después de cuatro décadas ha tenido lugar una mejora progresiva en la metodología llevada a cabo en la optimización en-línea, pero que siguen estando presente los puntos débiles originales. Tales aspectos están directamente relacionados con la detección del estado estacionario (o las frecuencias de las perturbaciones) y la optimización en sí misma.

Los objetivos de la presente tesis están dirigidos a solventar parcialmente tales puntos débiles de la metodología actual. Como resultado, se propone una estrategia alternativa que saca ventaja de las mediciones y busca una mejora continua en lugar de una optimización formal. Se muestra que tal estrategia resulta muy efectiva y puede no solo ser aplicada para la optimización de puntos de consigna, pero también para tomar (en-línea) las decisiones discretas necesarias en procesos que presentan degradación (aspecto normalmente resuelto usando programación matemática).

La estructura de la tesis es como sigue. El primer capítulo explica las principales motivaciones y objetivos del trabajo, mientras que el capítulo 2 consiste en una revisión bibliográfica que abarca, hasta cierto punto, los tópicos y funcionalidades más importantes asociados a la optimización en-línea. Luego, los capítulos 3 y 4 presentan la estrategia propuesta a través de dos metodologías para la optimización en-línea, lo cual es la contribución más importante de la tesis. El primero, (capítulo 3) se centra en la persecución de un óptimo que se mueve por el efecto combinado de perturbaciones externas e internas. Por otro lado, en el capítulo 4 se explica una metodología paralela, concebida para procesos que presentan desempeño decreciente con el tiempo y requieren decisiones discretas en relación a acciones de mantenimiento. Ambos capítulos incluyen una primera parte, más bien teórica, y una segunda parte dedicada a la validación usando casos de referencia. Luego, el capítulo 5 describe la aplicación de tales metodologías sobre dos escenarios industriales, con la intención de complementar los resultados obtenidos sobre los casos académicos. Posteriormente, el capítulo 6 aborda dos problemas asociados a la implementación: la influencia de los parámetros ajustables y la arquitectura del software usada. Finalmente, el capítulo 7 resume las principales conclusiones y observaciones de la tesis.

Acknowledgments

Asinus asinum fricat

I am in debt with many people that have made possible and pleasant my stay in the UPC Chemical Engineering Department. Although not in an exhaustive way, I would like to particularise hereinafter.

I thank Professor Luis Puigjaner for demonstrating so much trust in me, and I hope not to have defrauded him. Their push, decision and leadership have influenced strongly and favourably the development of my personality. His kind attitude towards me has worth my esteem and contributed to bear the difficult nuances of doctoral studies.

I also wish to also express my gratefulness to Marta Basualdo and Diego Ruiz who have motivated me to carry out the doctorate here (they are guilty and some day they will pay for that). Furthermore, both are guilty of being a fundamental support during my first steps of doctorate. Although the unbounded avarice for knowledge is a responsibility that I should rather attribute to my parents and sister to who, taking advantage of the occasion, equally I thank (today I feel kind).

I thank Moisès Graells for having me guided along my doctoral work. Their comments and suggestions have been always very valuable. The treatment, always friendly and close that, together to the freedom of action he gave me, have been very positive for my activities. Equally it is an honour to thank Antonio España for his very incisive critiques (to my works and to those of thirds). These have been of an extraordinary value for my professional development (I repeat: today I feel kind).

I can not leave without acknowledgments to, the today quasidoctor, Jordi Canton because his continuous help (and readiness for meriending) especially about computer topics, and having put up with my bad humour, when so (that is to say, every two days). I hope the patience shown by my right heard to its incessant and incomprehensible comments has rewarded his splendid attitude toward my (this time is not for pure kindness, to be honest I am trying to avoid to pay him a meal that I owe him).

I want to thank in particular to Miguel Herrera who so kindly has carried out the RTE parameter tuning simulations. I am also deeply grateful with Joan Manyà for...? (well, he is old enough to find a reason...).

I wish to express my sympathy and gratitude to every one of the doctorate candidates (Anna,

Acknowledgments

Claudia, Cristina, María José, Rosario, Suly, Chouaib, Dridi, Estanislao, Fernando, Gonzalo, Javier, José María, Kamal, Meng, Rodolfo, Saúl and Wondyfraw) as well to the engineering candidates (Aprilla, Txell, Alex, Dirk, Joel and Ricard) who have shared with me different stages of these four years of intense work. Similarly, it is not smaller my gratefulness to Quim and Mariana, essential individuals of the group.

I deeply thank to the Catalan, Spanish and European folks who through the UPC and the *Spanish Ministry of Science and Technology* have financed my Ph. D. study (FPI Grant).

I am also in debt with those that have contributed, directly or indirectly, with data and suggestions contained in this thesis: Compañía Azucarera Concepción S.A. (CACSA), Tucumán, Argentina; Complejo Agroindustrial Camilo Cienfuegos (CAICC), La Habana, Cuba; Instituto Cubano de Investigaciones de los Derivados de la Caña de Azúcar (ICIDCA), La Habana, Cuba; SOTEICA S.R.L., Buenos Aires, Argentina; Petroquímica La Plata, La Plata, Argentina.

Finally, my most valuable gratefulness to Nancy, for making me a so well accompanied man in life. Ah!, and to Lulu who always receive me so smiling!.

Sebastián Eloy Sequeira

Agradecimientos

Asinus asinum fricat

Estoy en deuda con muchas personas que han hecho posible y agradable mi estancia en el departamento de ingeniería química de la UPC. Si bien no de una forma exhaustiva, quisiera particularizar a continuación.

Agradezco al Profesor Luis Puigjaner por haberme demostrado tanta confianza, y espero no haberle defraudado. Su empuje, decisión y liderazgo han influenciado fuerte y favorablemente el desarrollo de mi personalidad. Su amable actitud para conmigo ha merecido mi estima, y contribuído a sobrellevar los matices arduos del doctorado.

Deseo expresar también mi agradecimiento a Marta Basualdo y Diego Ruiz por haberme motivado a realizar el doctorado (son los culpables y algún día me vengaré). Es más, ambos son también culpables de ser un soporte fundamental durante mi primeros pasos de doctorado. Aunque la avaricia desmedida por el conocimiento es mas bien una responsabilidad que debo atribuir a mis padres y hermana, a quienes, aprovechando la ocasión, igualmente agradezco (hoy estoy bondadoso).

Agradezco a Moisès Graells por haberme guiado a lo largo de mi trabajo doctoral. Sus comentarios y sugerencias han sido muy valiosos. El trato siempre amigable y cercano que me ha dado, unido a la libertad de acción otorgada, han sido muy positivos para mí. Igualmente es un gusto agradecer a Antonio España, por sus incisivas criticas (tanto a mis trabajos como a los de terceros). Estas han sido de un valor extraordinario para mi desarrollo profesional (repito: hoy estoy bondadoso).

No puedo dejar de agradecer al hoy quasidoctor Jordi Canton su continua ayuda (y predisposición al meriending) en especial acerca de temas de informática, y haber tenido que cargar con mi mal humor, cuando presente (o sea día por medio). Espero que la paciencia mostrada por mi oído derecho a sus incesantes e incomprensibles comentarios hayan recompensado su espléndida actitud hacia mí (esta vez no es por pura bondad, para ser honestos estoy intentando evitar pagarle una comida que le debo).

Quisiera agradecer en particular a Miguel Herrera, quien tan amablemente ha realizado las simulaciones del ajuste de parámetros de RTE. También estoy profundamente agradecido con Joan Manyà por...? (bueno que elija él no?, ya es grande...).

Pese a todo, quiero expresar mi simpatía y gratitud a todos y cada uno los doctorandos (Anna,

Agradecimientos

Claudia, Cristina, María José, Rosario, Suly, Chouaib, Dridi, Gonzalo, Javier, José María, Kamal, Meng, Rodolfo, Saúl y Wondyfraw, y hasta incluso Estanislao y Fernando) y a los ingenieros (Aprilla, Txell, Alex, Dirk, Joel y Ricard) quienes han compartido conmigo distintas etapas durante estos cuatro años de intensa labor. Por el bien de ellos, espero no volver a verlos. De igual modo, no menor es el agradecimiento a Quim y a Mariana, elementos esenciales del grupo.

Agradezco enormemente el apoyo de los pueblos catalán, español y europeo, quienes a través de la UPC y del *Ministerio de Ciencia y Tecnología Español* han financiado mis estudios de doctorado (beca FPI, de Formación de Personal Investigador).

Estoy también en deuda con aquellos que en forma directa o indirecta han contribuido con datos y sugerencias contenidas en esta tesis: Compañía Azucarera Concepción S.A. (CACSA), Tucumán, Argentina; Complejo Agroindustrial Camilo Cienfuegos (CAICC), La Habana, Cuba; Instituto Cubano de Investigaciones de los Derivados de la Caña de Azúcar (ICIDCA), La Habana, Cuba; SOTEICA S.R.L., Buenos Aires, Argentina; Petroquímica La Plata, La Plata, Argentina.

Finalmente, mi agradecimiento más preciado a Nancy, por hacerme un hombre tan bien acompañado en la vida. Ah!, y a Lulú por recibirme siempre tan sonriente!.

Sebastián Eloy Sequeira

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