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https://link.springer.com/article/10.1007/s00170-021-07682-3 – **Review on model predictive control: an engineering perspective**

Summary

- **Model Predictive Control (MPC)**: MPC is an advanced control method that utilizes a process model to predict future behavior of a controlled system. It determines the optimal control actions by solving a constrained optimization problem.
- **Applications and Benefits**: MPC is beneficial in fields requiring stringent control of complex systems like in the petrochemical and manufacturing industries. It handles constraints effectively and can optimize the control process based on the model predictions.
- **Computational Considerations**: MPC involves significant computational demands due to the necessity of solving optimization problems in real-time. Techniques to manage computational load include simplifying models or employing more powerful computational tools.
- **Implementation Challenges**: Implementing MPC can be challenging due to the need for accurate models and the computational requirements. Ensuring robustness and stability of the control system under various operational conditions is crucial.
- **Historical Context and Evolution**: MPC has evolved significantly since its inception, with improvements in both theoretical foundations and practical applications. Initial applications were focused in areas with slow dynamics, such as chemical processes, but have expanded into faster and more complex systems.
- **Future Trends**: The document discusses potential future developments in MPC, including integration with machine learning models for improved prediction capabilities, and expanding applications into new industrial areas.

Diagrams Breakdown:

1. **Figure 1**: Shows the yearly frequency distribution of scientific papers dealing with MPC formulation for buildings and HVAC systems. This graph is a bar chart representing the number of publications per year, highlighting a trend of increasing research and development in the field of MPC applied to building energy management.
2. **Figure 2**: Illustrates the principle of the receding horizon, a fundamental concept in MPC. This figure likely presents two sub-figures showing the shifting decision window as time progresses: one at the current time step and another at the next time step. This demonstrates how MPC continuously recalculates control actions based on updated predictions.

3. **Figure 3**: Provides a detailed framework of the MPC optimization problem applied to building and HVAC systems. This diagram might include various components such as the control objectives, constraints, disturbances, and the optimization algorithm. It visually organizes the relationship and flow between these elements, demonstrating how they interconnect to form the MPC strategy.
4. **Figure 4**: Likely shows different models involved in MPC problems, distinguishing scenarios with or without an actual controlled system. This figure could include flowcharts or system diagrams illustrating how theoretical models are adapted for real system implementations.
5. **Figure 5**: Depicts a typical example of an R-C (Resistance-Capacitance) network model used for MPC applications. This diagram probably shows how building thermal dynamics can be modeled using electrical circuit analogies, which are instrumental in simulating and predicting the thermal behavior of buildings under different control strategies.

Examples Provided:

- MPC Application Examples: The document might detail specific case studies or theoretical applications where MPC has been employed to improve energy efficiency in buildings. This could include examples of temperature control, air quality management, or integration with renewable energy sources.
- Modeling Approaches: Examples of different modeling techniques such as white-box, black-box, and grey-box models used in MPC to predict and optimize building performance.
- Control Strategies: Illustrative scenarios where MPC has been used to manage HVAC systems, highlighting how the control adjusts in real-time to changes in environmental conditions or occupancy patterns.

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https://www.mdpi.com/1996-1073/11/3/631 – **Model Predictive Control (MPC) for Enhancing Building and HVAC System Energy Efficiency: Problem Formulation, Applications and Opportunities**

Summary:

- **Focus and Relevance:** The document discusses the application of Model Predictive Control (MPC) in enhancing the energy efficiency of building operations and HVAC systems.

- **MPC Framework**: It explains the MPC framework, including problem formulation, the role of constraints, and the optimization process. The focus is on reducing energy consumption while maintaining comfort levels within buildings.
- **Applications:** Describes various applications of MPC in real-time energy management, demand response, and integrating renewable energy sources.
- **Advantages:** Highlights the benefits of MPC such as improved energy efficiency, optimal use of resources, and enhanced system responsiveness.
- **Challenges and Opportunities**: Discusses the challenges like computational demands, model accuracy, and real-time implementation. Opportunities in further integrating MPC with IoT and smart technologies are also explored.

Diagrams Breakdown:

- **Figure 1**: Shows the yearly frequency distribution of scientific papers dealing with MPC applications in building and HVAC systems. This graph illustrates the increasing research interest and publications over the years.
- **Figure 2**: Presents a schematic of the receding horizon principle in MPC. It visualizes how the control strategy updates at each time step, optimizing future system responses based on current data.
- **Figure 3**: Depicts the framework and critical elements of the MPC optimization problem applied to building and HVAC systems. This diagram categorizes various factors influencing MPC models, such as disturbances, objectives, and constraints.
- **Figure 4**: Illustrates models involved in MPC problems, differentiating between scenarios with or without a real controlled system. It distinguishes between the theoretical model formulation and practical implementation setups.
- **Figure 5**: Represents an R-C network model used in MPC applications, showing how electrical circuit analogies are applied to model thermal dynamics in buildings.

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Summary:

- Introduction to Model Predictive Control (MPC):
    - Definition: MPC computes a sequence of manipulated variable adjustments to optimize the future behavior of a plant.
    - Evolution: Originally developed for power plants and petroleum refineries, MPC now finds applications across a diverse range of industries including chemicals, food processing, and more.
- Historical Development of MPC:
    - Early Concepts: The development of MPC was influenced by the work of Kalman on Linear Quadratic Regulator (LQR), which established a framework for optimal control.
    - Industrial Adaptation: MPC was adapted for industrial use to handle constraints, nonlinearities, model uncertainties, and specific performance criteria which were challenging for traditional control strategies.
- MPC Algorithm Overview:
    - Control Formulation: MPC involves solving an optimization problem that incorporates future predictions of plant behavior to determine optimal control actions.
    - Receding Horizon Principle: MPC uses a rolling optimization approach where the control solution is continuously updated based on new data.
- Vendor Survey and Technological Diversity:
    - Survey Conducted: The paper surveys various MPC vendors to gather insights on different MPC technologies available commercially.
    - Findings: The survey highlights the diverse approaches and specializations of different vendors, reflecting the adaptability of MPC technology to various industrial needs.
- MPC Control Algorithms:
    - General MPC Framework: Describes a generic MPC control algorithm used as a standard by various vendors.
    - Vendor Specific Algorithms: Details on specific adaptations and enhancements made by different vendors to improve performance or to cater to specific industrial applications.
- Identification Technologies in MPC:
    - Importance: Identification technology is crucial for accurately modeling the plant dynamics which MPC relies on.
    - Techniques: Review of various approaches to system identification, including black-box, grey-box, and white-box modeling, each with its strengths and suitable applications.
- Applications and Case Studies:

        - Wide Applications: Detailed examples of MPC applications across industries demonstrating its versatility.
        - Specific Examples:
            - Power Plant Steam Generators: MPC helps in managing the steam output to turbines.
            - Fluid Catalytic Cracking Units: MPC controls the cracking process for optimal output in petroleum refineries.
            - Pyrolysis Furnace Temperature Control: Use of MPC to maintain optimal temperature, enhancing operational efficiency and product quality.
- Future Directions and Enhancements:
    - Next-Generation MPC: Discussion on the potential future developments in MPC technology including integration with advanced computational tools like AI and IoT.
    - Business and Research Opportunities: The paper concludes with a vision for expanding the business applications of MPC and areas for further research.

Diagrams and Examples:

- Figure 1: Shows a state space model which includes variables and equations representing the system dynamics MPC aims to control. This diagram helps understand the foundational mathematical model behind MPC systems.
- Figure 2: Depicts a hierarchical control structure comparing traditional control methods against MPC. This illustration is critical in understanding how MPC integrates into existing systems and enhances control capabilities.
- Examples:
    - DMC Technology: An example of Dynamic Matrix Control (DMC), an early form of MPC developed by Shell, which uses a linear step response model to predict future plant outputs based on historical input data.
    - QDMC Approach: Quadratic Dynamic Matrix Control (QDMC) incorporates both input and output constraints directly into the MPC formulation, enhancing the robustness and effectiveness of the control system.
    - Applications in Different Industries: The document lists specific examples of MPC applications such as controlling a power plant's steam generator, a fluid catalytic cracking unit in petroleum processing, and temperature control in a pyrolysis furnace.

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https://www.sciencedirect.com/science/article/pii/S1474667016414448 – Embedded Model Predictive Control (MPC) using a FPGA

Summary

- Title and Authors:
  - "Embedded Model Predictive Control (MPC) using a FPGA"
  - Authors: K.V. Ling, B.F. Wu from Nanyang Technological University, Singapore; J.M. Maciejowski from Cambridge University, UK.
- Abstract and Key Focus:
  - Focus on implementing Model Predictive Control (MPC) on Field Programmable Gate Arrays (FPGAs) to enhance computation speeds.
  - Emphasizes the exploration of parallel computation on FPGAs to achieve speeds comparable to those on a Pentium 3.0 GHz PC.
- Introduction:
  - MPC has expanded from petrochemical industries to high bandwidth applications like aerospace and automotive sectors.
  - The paper argues for hardware acceleration of MPC using FPGAs to meet the high-speed requirements of embedded systems.
- MPC and FPGA Implementation:
  - Previous work involved sequential computation on FPGAs.
  - Current focus: Leveraging parallel computation capabilities of FPGAs to speed up MPC implementations.
- MPC Formulation Review:
  - MPC typically solves quadratic programming (QP) problems defined by system states, inputs, and outputs.
  - Explains the transition of MPC problems to a QP format suitable for FPGA implementation.
- Interior Point Method for QP:
  - Detailed explanation of the Interior Point method used for solving QP problems related to MPC on FPGAs.
  - Description of iterative process adjustments in FPGA implementations for optimization.
- Prototyping Environment:
  - Utilizes MATLAB for simulation and FPGA boards for actual MPC implementation.
  - Describes tools and resources used, including specific FPGA boards and software environments.
- Implementation Examples and Verification:
  - Describes an aircraft model simulation to verify FPGA implementations.
  - Discusses constraints and limitations in detail, including pitch and elevation angles.

Explanation of Diagrams and Examples

- Fig. 1 - Prototyping of MPC on a Chip:
    - Diagram illustrating the setup for MPC prototyping, integrating MATLAB simulations with FPGA hardware implementations.
    - Shows the flow from system modeling in MATLAB to real-time control implementation on FPGA.
- Figures 4(a) and 4(b) - Sequential vs. Parallel Implementation:
    - Illustrates code fragments showing how the same computation task is implemented in a sequential and parallel manner on FPGA.
    - Figure 4(a) shows a sequential computation requiring more clock cycles.
    - Figure 4(b) demonstrates parallel computation reducing clock cycles by executing tasks simultaneously.
- Simulation Results - Aircraft Model and Constraints:
    - Uses a detailed example of a Cessna Citation 500 aircraft to demonstrate the application and validation of FPGA-based MPC.
    - Discusses the constraints related to aircraft control, such as elevator angle and slew rate, and how they are managed within the MPC framework.
- Performance Comparison:
    - Table 1 in the document compares computational times for different MPC implementation schemes, highlighting the efficiency gains from parallel processing on FPGAs.

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https://ieeexplore.ieee.org/abstract/document/782911?casa_token=SKTNHCOnqPUAAAAA:hgK09wBIsirRXtvGM-NAN5eVZky4v-vVMb98l1VFvtXa9gxaPLE3r-gitpZfm2DXxQBICns –

Tutorial: model predictive control technology

Detailed Bullet-Point Summary

- Introduction and Overview:
    - Provides a tutorial on model predictive control (MPC) for both linear and nonlinear models.
    - Discusses various MPC aspects like steady-state target calculation, infinite horizon control, resolving constraints, state estimation, and disturbance models.
    - Targets control practitioners, aiming to enhance their understanding of MPC implementation and challenges.

- Linear Models:
    - Early industrial MPC applications favored time-domain models due to their simplicity.
    - Transition to discussing linear models in state-space form, highlighting advantages such as ease of analysis, generalization to multivariable systems, and online computation.
    - Discusses constraints within MPC formulations, emphasizing input constraints and their transformation into nonlinear control problems.
- Nonlinear Models:
    - Advocates for using nonlinear models to improve control accuracy due to more realistic modeling of physical phenomena like chemical kinetics and energy conservation.
    - Highlights the challenge in identifying appropriate models from purely empirical to those based on fundamental principles.
- MPC with Linear Models:
    - Formulates MPC as an infinite horizon optimal control strategy using quadratic performance criteria.
    - Describes integration of state estimation into MPC to manage unmeasured disturbances and achieve offset-free control.

Diagrams:

- Figure 1: Shows input and state constraint regions, demonstrating how constraints shape control actions within the feasible region.
- Figure 2: Illustrates hypothetical constraint regions for another scenario, helping visualize how MPC adapts to different operational constraints.

Examples:

- Aircraft Model Example: Detailed example using an aircraft model to illustrate the effectiveness of FPGA-based MPC implementations, showing how hardware acceleration can be optimized to enhance computational speeds.
- State Estimation:
    - Discusses the integration of state estimation in MPC to manage the effects of model inaccuracies and disturbances.
    - Emphasizes the importance of accurate disturbance modeling to ensure robust control performance.
- Nonlinear MPC:
    - Explores the challenges and potential of nonlinear MPC, noting the gap between theoretical desirability and practical implementation challenges.
    - Discusses current research efforts to make nonlinear MPC feasible and robust.

- Future Developments:
  - Suggests areas for future research in MPC, including robust MPC, moving horizon estimation, and the application of MPC to hybrid systems involving both continuous and discrete components.

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https://www.sciencedirect.com/science/article/pii/B9780080357355500061 – Model predictive control: Theory and practice

Summary

- Introduction and Scope:
  - The document covers the theory and practical aspects of Model Predictive Control (MPC), a control technique using explicit models for prediction and control design.
  - Emphasizes the popularity of MPC in industrial applications due to its high performance and ability to operate without expert intervention for extended periods.
- Core Concepts:
  - MPC involves direct use of an explicit and separately identifiable model to predict and control process behaviors.
  - Distinguishes between different MPC design techniques like Dynamic Matrix Control (DMC), Model Algorithmic Control (MAC), Inferential Control, and Internal Model Control (IMC).
- Advantages of MPC:
  - Capability to handle flexible constraints effectively, crucial for operational objectives in process industries.
  - Suitable for various norm formulations (1-norm, 2-norm, and infinity-norm) for performance objectives.
  - MPC's design and implementation benefits are contrasted with traditional methods like Linear Quadratic Control.
- Application in Nonlinear Systems:
  - The document notes that MPC applications to nonlinear systems are not covered extensively due to the focus on linear systems in this tutorial.
- Robustness of MPC:
  - Discusses the robustness of MPC, indicating it can be adjusted easily for robustness though it is not inherently more or less robust than classical feedback control systems.

- Historical Background and Evolution:
    - Traces the development of MPC back to key papers in the late 1970s that described successful applications and theoretical foundations.
    - Describes the evolution from heuristic predictive control to more structured approaches like DMC.
- MPC Algorithm Formulations:
    - Explains how the MPC control problem is formulated as a dynamic optimization problem, highlighting the process and methodologies used to derive specific algorithms such as DMC and MAC.
- Models and System Representation:
    - Discusses the use of different system representations in MPC, including state-space models and transfer matrix models, emphasizing their importance for accurate predictions and control.
- Implementation Challenges and Industry Applications:
    - Notes the computational challenges associated with real-time implementation of MPC.
    - Provides examples of industry applications demonstrating the versatility of MPC in handling complex, multivariable systems with constraints.
- Future Directions:
    - Mentions areas for future research in MPC, particularly in optimizing computational approaches and extending applications to handle nonlinear systems and uncertainties more effectively.

Explanation of Diagrams and Examples

- Diagram Explanation:
    - Typically, diagrams in such documents would illustrate concepts like the feedback loop of MPC, showing how the controller receives data, makes predictions, and adjusts controls accordingly.
    - Other diagrams might visually represent the comparison between MPC and other control methods, or show the flow of information within an MPC system.
- Example Details:
    - Specific examples, if illustrated, would likely include case studies of MPC applications in industries like chemicals or petroleum where MPC has been used to optimize processes subject to constraints.
    - These examples would demonstrate how MPC adapts to changes in process conditions or operational goals, optimizing control actions based on model predictions.

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https://www.researchgate.net/profile/Mohamed-Mourad-Lafifi/post/Only_the_RMPCT_package_provides_robust_tuning_in_an_automatic_way_does_it_work_for_non-minimum_phase_systems/attachment/59d6404079197b807799c82b/AS%3A430209804574720%401479581418769/download/An+Overview+of+Model+Predictive+Control.pdf – An Overview of Model Predictive Control

Summary

- Introduction to Model Predictive Control (MPC):
  - Emphasizes the explicit use of a model to derive control signals.
  - Highlights the flexibility and effectiveness of MPC in handling various industrial control challenges.
  - Common MPC strategies covered include Dynamic Matrix Control (DMC), Model Algorithmic Control (MAC), and Generalized Predictive Control (GPC), among others.
- Historical Background of MPC:
  - Originated from the need to improve upon limitations of other control methods like PID controllers, which are less effective for plants with significant time delays.
  - Development influenced by early works in the 1970s by engineers at Shell Oil and further advancements by various researchers focusing on robustness and adaptability.
- Core MPC Strategies Explained:
  - Dynamic Matrix Control (DMC): Uses step responses of the plant for future output projection, suitable for stable processes.
  - Model Algorithmic Control (MAC): Similar to DMC but uses impulse responses and is effective in multivariable control scenarios.
  - Predictive Functional Control (PFC): Utilizes a model to predict future control paths with an emphasis on robustness, typically employing state-space models.
  - Extended Prediction Self-Adaptive Control (EPSAC): Focuses on enhancing predictability with adaptive control mechanisms.
  - Generalized Predictive Control (GPC): A versatile strategy using CARIMA models to handle both constant and varying set points efficiently.
- Advantages of MPC:
  - Ability to handle constraints more effectively than conventional controllers.
  - Suitable for complex multivariable processes often encountered in industrial settings.
  - Improved adaptability to changes in system parameters, enhancing robust control.

- Challenges and Considerations:
    - Computational demands due to the real-time optimization of control actions.
    - Requirement for accurate models to effectively predict future plant behaviors.

Explanation of Diagrams

- Figure 1: Moving Horizon Strategy of MPC:
    - Illustrates how MPC recalculates control actions at each time step based on updated predictions. The diagram likely shows the horizon moving forward as new data is received, emphasizing the dynamic and adaptive nature of MPC.

Examples Explained

- Industrial Applications:
    - Examples in the document likely detail the application of various MPC strategies in industries such as chemicals, petroleum, and power generation.
    - Specific case studies might demonstrate the implementation of MPC in controlling complex processes like distillation columns or energy management systems, highlighting the improvements in efficiency and compliance with safety standards.

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https://www.sciencedirect.com/science/article/pii/S0005109809004427?casa_token=P0iH_kypFiYAAAAA:xN7396wBDRQShV9GL_6QxsLiumFw5ZmLLEEXFv--cpbRWYS-exD-3107pI6RkMB7CDlB4pw – Multiobjective model predictive control

Summary

- Introduction and Context:
    - Explores the integration of multiple performance criteria within the MPC framework, highlighting the complexity of balancing conflicting objectives such as efficiency and safety.
    - Discusses earlier works and the progression from single-objective to multiobjective MPC, acknowledging foundational theories and significant contributions from various researchers.
- Multiobjective Optimization:

- Introduces multiobjective optimization by detailing how traditional MPC is extended to handle multiple, often conflicting objectives by optimizing a weighted sum of these objectives.
- Explains Pareto optimality in the context of control systems, where a solution is considered Pareto optimal if no objective can be improved without degrading another, providing a mathematical definition and its relevance.

- Problem Formulation:
    - Presents a linear discrete-time system model used in the formulation, describing how state and control input constraints are incorporated into the MPC framework.
    - Sets up a multiobjective optimal control problem, defining multiple performance indices and their roles within the MPC strategy, including constraints and terminal conditions.
- Proposed MPC Scheme:
    - Details an MPC scheme that selects control actions from Pareto optimal solutions using a dynamic weighting system that depends on the system's state and desired performance criteria.
    - Explains the algorithm used to adjust weights over time to maintain system stability while meeting performance targets, illustrating how the MPC recalculates decisions at every time step.
- Stability Analysis:
    - Provides a thorough analysis and proof of stability for the proposed MPC approach, explaining the conditions under which the system remains stable.
    - Discusses the application of Lyapunov stability principles to ensure that the proposed control law results in a stable system trajectory under all specified operating conditions.

Explanation of Diagrams

- Diagrams of System Model and MPC Strategy:
    - Diagrams likely include representations of the system model, showing how inputs, states, and outputs are interrelated within the MPC framework.
    - Illustrations of the control loop, possibly flowcharts or block diagrams, showing how data flows through the system, how decisions are recalculated, and how stability is maintained.

Examples Explained

- Simulation Examples:

- Detailed discussion of simulation setups used to validate the proposed MPC strategy, including descriptions of system parameters, control objectives, and the criteria used for performance evaluation.
- Specific examples might include the control of industrial processes where efficiency and safety conflict, illustrating how different weighting strategies affect system performance.

Key Contributions and Conclusions

- Detailed Contributions:
  - Emphasizes the novelty of integrating dynamic, state-dependent weighting of objectives into the MPC to handle real-time changes in system conditions or operational priorities.
  - Discusses the implications of this approach for industries where rapid response to changing conditions is critical, such as aerospace or chemical processing.
- Conclusive Insights:
  - Concludes that multiobjective MPC can significantly enhance the adaptability and efficiency of control systems in complex environments.
  - Suggests future research directions, such as further integration with real-time learning algorithms to dynamically update models or objectives based on incoming data.