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Recent Trends in Model Predictive Control

Srikshana Sasidaran, Adithya R., Haris Raja V., M.P.Anbarasi
Department of Robotics and Automation Engineering
PSG College of Technology,
Coimbatore, India.

Abstract:- In this paper we are going to present the recent trends of model predictive control (MPC) and its techniques are used in modern world. MPC forecasts plant output behavior using a plant model. The MPC controller solves the optimization problem across the prediction horizon while adhering to the constraints at the current phase. This can be used in non-linear problems and it is more precise when compare to the linear controller such as PID.

Keywords:- *Model Predictive Control, Feedback Control Strategy, Dynamic Control Algorithms.*

I. INTRODUCTION

The controller's purpose in a control problem is to compute the input to the plant so that the plant output follows the desired reference. The technique used by a Model Predictive Controller to compute this input is to forecast the future.MPC predicts plant output behavior using a model of the plant. It also employs an optimizer to verify that the expected future plant production corresponds to the targeted reference. The following example demonstrates these stages. Assume that there is an autonomous automobile is kept true to the path by means of an MPC controller.MPC can handle MIMO systems like this one, but for the sake of simplicity, it is assumed that the accelerator is fixed, the automobile is moving at a constant speed, and only the steering wheel angle is adjustable to regulate the lateral position of the car.MPC is known as the prediction horizon since it looks into the future. It is frequently expressed as the number of future time steps or the length of time into the future. The MPC controller must locate the best-predicted path that is closest to the reference. As a result, it models a variety of future possibilities. However, it does not perform these simulations in a random sequence. Instead, it does so in a methodical manner.

Furthermore, this is where the optimizer comes into play. The MPC controller reduces the error between the car's reference and forecasted paths by solving an optimization problem. It also strives to keep the steering wheel angle change from one step to the next to a minimum. Because the steering wheel is twisted sharply, the passengers may find the ride unpleasant. This optimization problem's cost function J incorporates both terms and is written as a weighted squared sum of standard errors and steering wheel angle increments. MPC ensures that the steering wheel angle and vehicle position remain within prescribed limits while reducing this cost function. These are referred to as constraints. There is a limit to how far the steering wheel maybe maneuvered. Another constraint is the placement of the automobile. To avoid accidents, the vehicle is designed to stay inside its lane and not wander off the road.The MPC controller solves the optimization issue across the prediction horizon while meeting the restrictions at the present step. The anticipated route with the J provides the best solution and selects the best steering wheel angle sequence to bring the automobile as near the reference as feasible. MPC only applies the initial step of this optimum sequence to the automobile at this time step and ignores the rest. The automobile moves a certain distance based on the steering wheel angle used.

The controller receives a new measurement of the car's lateral position at the following time step. It may differ somewhat from what the MPC controller projected previously. This might result from an unmeasured disturbance operating on the vehicle. For example, it may be the wind or a slick road surface. The prediction horizon is moved ahead by a single step, and the controller performs the same cycle of computations to determine the ideal steering wheel angle for the next step. MPC is also known as receding horizon control due to the forward-moving aspect of the prediction horizon. For example, it may be the wind or a slick road surface.

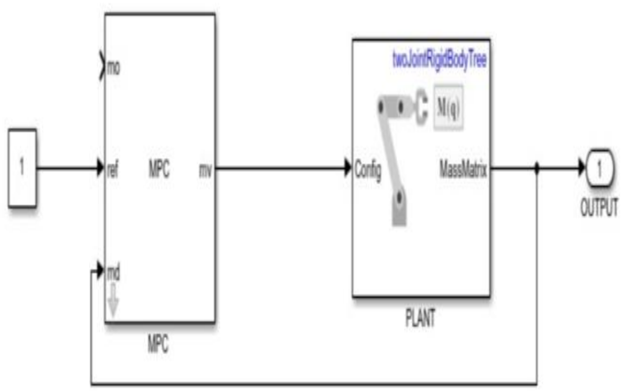

Fig 1: Model Predicitve Controller

The prediction horizon is moved ahead by a single step, and the controller performs the same cycle of computations to determine the ideal steering wheel angle for the next step. MPC is also known as receding horizon control due to the forward-moving aspect of the prediction horizon.MPC is referred to in textbooks using general terms. The signals generated by the controller and supplied to the plantare referred to as manipulated variables, while the plant outputs are referred to as output variables. In the feedback diagram, State estimator can be observed. In the automobile example, it is assumed that the lateral position of the car could be measured. However, if the states of a system cannot be directly measured, they can be inferred by a state estimator and supplied back to the MPC controller.

II. NEED FOR MODEL PREDICTIVE CONTROL

MPC, which is maybe the most common control among specific engineers. However, it stands for model predictive control. MPC is a feedback control method that makes predictions about a process's future outputs using a model.Initially simulations are run in the brain using the resulting model. These forecast the future trajectory based on the control actionsselected. Thenthe best action to bring the anticipated trajectory as near the desired trajectory as feasible is chosen.These are some of the reasons why model predictive control is employed.MPC is capable of dealing with multi-input and multi-output systems that may have interactions between their inputs and outputs[Fig 2]. In this MIMO system, adjusting the second output influences the first output. IfPID controllers are used, constructing them would be difficult since the two control loops would work independently as if they had no relationships. Furthermore, constructing more effective systems would be significantly more complex, necessitating the tweaking of far too many controllers' gains

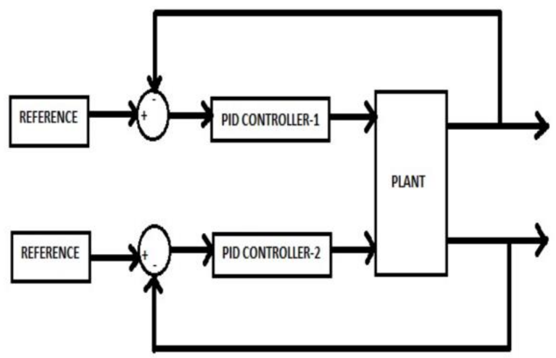

Fig 2: MIMO System with MPC

MPC has the advantage of being a multivariable controller that regulates the outputs simultaneously while accounting for all system variable interactions. Another feature of MPC is its ability to deal with constraints. Constraints are required because breaching them may result in unforeseen consequences. One of the driving safety constraints, for example, is that autos must adhere to speed regulations and maintain a safe distance from other vehicles. Other controls, such as acceleration limits, are imposed by the car's physical limitations. If this were a self-driving automobile driven by MPC, the controller would follow a desired trajectory while adhering to these limits. MPC also has a preview function, which is akin to feedforward control. Assume the autonomous vehicle is traveling on a winding road. If the controller is unaware that a corner is approaching, it will only apply brakes while entering the corner. However, if the automobile includes a front-facing camera that provides information about the vehicle's future trajectory, the controller will be aware of the forthcoming corner in advance. As a result, it may break sooner in order to stay in the lane safely. To increase controller performance, MPC may readily include future reference information into the control issue.

Since the 1980s, Model Predictive Controllers have been employed in the process sector. Microprocessors' application has extended to different sectors as their computational capacity has increased.MPC provides all of these advantages, but it is essential to remember that it demands a robust and fast CPU with enough memory. The reason for this is that MPC solves an online optimization issue at every time step.MPC uses a system's model to anticipate its future behavior and then solves an online optimization algorithm to choose the optimal control action that drives the expected output to the reference. It can operate Multi-Input Multi-Output systems that may have input-output interactions.MPC can deal with restrictions and has preview capabilities. It is also frequently employed in a variety of sectors.

III. RELATED WORKS

A. Development of a Model Predictive Controller for an Unstable Heavy Self-balancing Robot

This Model Predictive Controller based approach is applied to a Two- wheeled Self-Balancing robot which is of heavy weight. Two wheeled Self balancing robot is similar to Segway. It is also similar to Inverted Pendulum [2].

Many Non-Linear equations are present in a Two-Wheeled Self Balancing Robot. The robot is first controlled using a classic PID controller. Closed loop PD controller is used to drive the robot. Manually tuned Kp and Kd values are fed into the system. Then Model tuning for the system is done to reduce the error. The obtained model is used to calculate Open loop step response which can be used in Model Predictive controller (MPC).The manipulated variable in MPC is the Motor Speed and the controlled variable is the Tilt Angle. The Parameters of the algorithms are tuned and final parameters are obtained.MPU algorithm works efficiently compared to the output of PD controller. The linear model gives only approximate results whereas MPC stabilizes the robot for even a strong disturbance in a short span of time.

B. Design and Development of Model Predictive Controller for Binary Distillation Column

The concept proposed here with employs a Model Predictive Controller in the Industrial Binary Distillation Column [23]. The purification of final products in Petroleum and Chemical Industries is done by a separation process called as Distillation. Mass transfer or heat energy transfer is enhanced using Distillation process.The control inputs of this configuration are the vapor flow rate and liquid flow rate. The objective of this model is to maintain the output product concentration due to disturbance in feed rate and feed concentration. The basic idea is to reduce the error and to predict the future response of the distillation system. The system is tested with general PID controller as well as with Model Predictive Controller using SISO and MIMO systems. MPC takes into account of the input variables and the manipulated output variables and the control variable output is obtained by minimizing the cost function [Fig 3].Wood and Beery Binary distillation system is taken and PID and MPC controller is applied to the system. The MATLAB and

Model Predictive Tool Box is used for the simulation of the system.

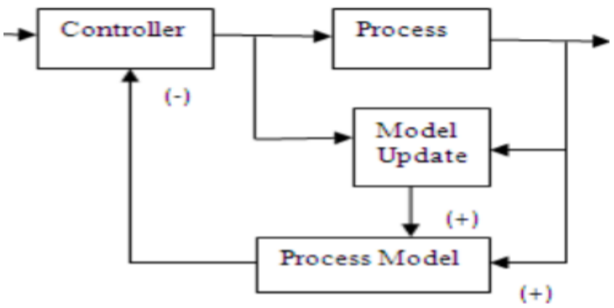

Fig. 3: Structure of MPC

The performance of the MPC controller is compared with that of the traditional PID controller. Based on the proceedings of the paper, it can be presumed that MPC controller shows better results compared to PID controller. MPC controller provides smooth reference tracking, peak overshoot is reduced significantly and better closed loop performance.

C. Model Predictive control and Optimization for Papermaking process

Large scale 2-Dimensional process is involved in papermaking process. Machine direction control and Cross direction control are the two challenges to overcome in the process of papermaking [6].MPC offers a variety of uses in paper machine control. MPC handles basic MD control and advanced MD-MPC control, which includes economic optimization and orchestrates transitions across paper grades.Cross direction can be controlled using MPC, using a properly determined solution approach.The papermaking CD method is a two-dimensional system with a vast size. It has a high level of input-output coupling. MPC is a common approach for regulating multivariable systems, and it has evolved into a common advanced control strategy in papermaking systems. However, mill staff have various challenges in accepting CD-MPC, including the unique multivariable control concept and the non-trivial tuning approach.CD-MPC has been successfully implemented in over 70 paper mills and has been applied to virtually all types of existing CD processes, including fine paper, board, newsprints, tissues, and so on. Over the next decade, CD-MPC will undoubtedly have a substantial influence on papermaking CD control applications.The ability to combine numerous CD actuator arrays and multiple CD measurement arrays into a single CD controller is a key advantage of CD-MPC.Non-standard CD measurements, such as fiber orientation, gloss, web formation, and web porosity, are anticipated to be included into the existing CD-MPC framework in the next generation of CD-MPC applications.

IV. TYPES OF MODEL PREDICTIVE CONTROL AND ITS APPLICATIONS

The Model Predictive Control method became a futuristic necessity because almost all of the industrial processes are developing and becoming more and more intricate in leaps and bounds. At one point, these industrial processes are bound to attain such a level of complexity that it will become impossible for the traditional methods to comprehend and process the data. This is where the Model Predictive Control algorithm comes into play.This control algorithm is one of the most or the most versatile and compatible algorithms to ever exist. This is because; this control strategy can be combined with any one algorithm or piece of code to form a completely new type of control algorithm. These combined algorithms are called or referred to as hybrids[Fig 4]. To provide a comprehendible illustration, the predictive control algorithm can be combined with engineering economics to form the economic non-linear model predictive control strategy.Neural Networks can be combined with the model predictive control to form an optimal non-interfering administering algorithm.

Prediction Algorithm	Applications
Fuzzy Control	Heating and cooling of buildings
Neural Network Control	Control of thermal processes for energy saving purposes
PID Control	Furnace chamber pressure
Adaptive Control	Altitude Control of Quad rotor

Fig 4: MPC hybrid algorithms and their applications

V. BENEFITS OF THE MUTATIONS OF MODEL PREDICTIVE CONTROL STRATEGY

The Model Predictive Control Strategy can be surprisingly rewarding, despite its predicaments due it its infant stage. One of the most common drawbacks present in the prevailing control strategies is that it cannot sustain commanding multiple input and output devices at a time. But when it comes to the Model Predictive Control algorithm and its hybrids can handle multiple input and multiple output devices with such ease. These algorithms have the capacity to make constrained processing of the data to seem like child's play.

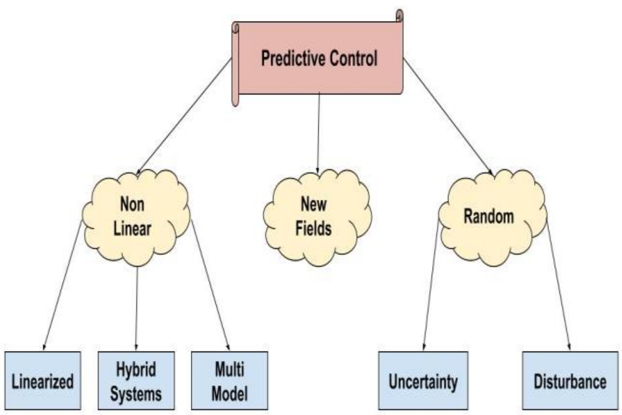

Fig 5: Types of MPC fields

Initially, the predictive control strategies are divided into three categories [Fig 5], namely
- Non-linear
- New up and coming fields
- Random fraternity.

The non-linear category can further be divided into three sub-categories namely, linearized applications, multi-model practices and hybrid systems. The multi-model approach is used to facilitate the approximation of non-prismatic operation variables. And the hybrid systems can help with constantly varying dynamic processes with the help of logical switching techniques.When it comes to the random applications, it exercises the concept of probabilistic uncertainty. This can be classified into two categories as
- Uncertainty and
- Disturbance.

VI. IMPEDIMENTS IN THE APPROACH

Since the Model Predictive Control strategy is an up-and-coming field in the fraternity of manipulator control and trajectory planning, there are a variety of complications and hardships that has to be worked around. The drawbacks and problems posed by this method can be distinguished into many diverse points of views including from the algorithm, object application and computing necessities. Some of the most prominent ones are listed below:
- In its primitive stage, the MPC method can be applied only in scale-based applications in production.
- This control algorithm requires computers that have high processing and performance capabilities and also considerably depreciates the dynamic operations.
- Due to the rising requirements of the MPC algorithm, it substantially hinders the possibility of development in not only applications but also in space consumption.
- It is very difficult for the normal, orthodox computers and similar devices that is used on a day-to-day basis to calculate the real time data obtained from this method.
- Since this control method is still in its development stage, this is not one of the most accurate systems to exist.
- When the Model Predictive Control strategy was applied in real time applications in the industries, it could only satisfy the initial industrial standard requirements.
- When it comes to optimizing the non-linear problem statements, this approach lacks the procession of proper effective algorithms.
- For this method to be successful, it has to compute and calculate a huge amount of data. Thus, this leads to the computing requirements of this algorithm to be fairly massive.
- This control strategy utilizes a large amount of online data and applications. So, this method might not be as economically feasible like other alternate methods.
- The Model Predictive Control strategy is still in incubation. Hence, there is a huge disconnect between its theoretical possibilities and its practical applications.
- The remunerative and gregarious enlargement and evolution rate of this approach remains unmet.

VII. PROSPECTS OF MODEL PREDICTIVE CONTROL STRATEGY

The Model Predictive Control method when proved practically and economically viable can provide to be useful in a diverse range of applications be it either large scale intricate systems or non-linear systems.Though this prospective is quite a challenge to achieve, this control algorithm can be used to administer the large-scale applications like sewage disposal systems and management systems of urban traffic. This method can prove to be advantageous due to its disturbance soundness, global stability and confluence capabilities.This method can also be utilized in rapid moving applications be it the aerospace fraternity or electro-mechanical applications. The Model Predictive Control algorithm has been successfully proven in comparatively slower dynamic processes, but has been pretty difficult to achieve sustainable efficacy in procedures that require a massive number of computations to process the data.But when it comes down to the non-linearized applications, this method needs to utilize a titanic amount of data, calculations and processing iterations to operate efficiently. Due to these hazards, this has not been implemented in more well aged practical operations.

The Model Predictive Control strategy can also be utilized for controlling and monitoring non-domestic buildings as it highly brings down the emissions of Carbon-di-oxide when compared with the pertaining restrained control systems and strategies. In addition to that, this algorithm also proves to be an economically sustainable alternative to the existing monitoring systems present in full scale buildings and skyscrapers. The energy efficiency offered by this method is one of the best alternatives to have been developed.

When it comes to power plants and power stations that use gas turbines fueled by biomass and natural gases to generate electricity, the Model Predictive Control algorithm can be availed to increase the performance metrics during the startup of the plant. This can be achieved by minimizing the time it takes to attain the desired set point and by avoiding the unforeseen catastrophic and hazardous situations that can happen when starting up the plant.

VIII. CONCLUSION

Model Predictive Control is one of the most promising feedback control strategies to be employed given its ability to prospectively facilitate not only online optimization, but also enables the industrial processes to be controlled with way more efficacy than the present prevailing systems. MPC can be implemented in MIMO systems in contrast to other conventional controllers which can handle only SISO systems. In spite of the absence of any visible connects between this feedback control strategy and the level of its practicality in the day-to-day industrial operations, this algorithmic approach has the better aspect of being well suited for a multitude of applications in a variety of industries like healthcare, shipping, transport, energy, urban development, agriculture and aerospace.

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