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Fluid Level Control Using Predictive Control algorithm MPC

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ABSTRACT :

The MPC (Model Predictive Control) algorithm is a model-based control technique, where a mathematical model of the process being controlled is used to predict its future behaviour. The algorithm calculates a series of optimal control inputs in the future to achieve specified control objectives, given system constraints. The first value in this series is then applied to the system, and the process is repeated cyclically. In this paper we will build a water storage tank system, MPC can be used to control the water level in the tank. The water level is continuously measured, and this value is used to update the model and determine the required flow value of the outlet valve to maintain the target water level. MPC can handle fluctuations in water demand and changes in rainfall.

Keywords:- State Space Form , water tank, MPC algorithm, fluid level control

1. Introduction :

MPC (Model Predictive Control) is one of the advanced algorithms in the field of automatic control that has gained great popularity in recent years. This algorithm is characterized by its ability to deal with complex dynamic systems, and provide high-precision and stable control performance. In this paper, we will review the concept of MPC algorithm, how it works, and its various applications in industry.

The MPC algorithm is a model-based control technique, where a mathematical model of the process being controlled is used to predict its future behavior. The algorithm calculates a series of optimal control inputs in the future to achieve specified control objectives, given system constraints. The first value in this series is then applied to the system, and the process is repeated cyclically.

How does MPC work?

Model building: A mathematical model of the controlled process is built, which describes the relationship between inputs and outputs.

Prediction: The algorithm uses the model to predict the future behavior of the system based on current and predicted input values.

Optimization: The algorithm calculates a series of optimal control inputs that minimize the prediction error and maintain the system within the specified constraints.

Application: The first value from the calculated input series is applied to the system.

Iteration: Steps 2 through 4 are repeated cyclically.

Advantages of MPC Algorithm

Dealing with constraints: MPC can deal with a wide range of constraints, such as constraints on inputs and outputs, and constraints on variables internal to the system.

High performance: MPC offers high-precision and stable control performance, especially in complex and nonlinear systems.

Prediction of the future: MPC allows the system to predict the future and make control decisions based on this prediction.

Flexibility: MPC can be applied to a wide range of industrial processes.

MPC Algorithm Applications

The MPC algorithm is widely used in many industrial applications, including:

Oil and gas industry: control of refining and petrochemical processes.

Energy industry: control of power plants.

Automotive industry: control of internal combustion engines.

Aerospace industry: control of aviation systems.

Environmental processes: control of water and air treatment processes.

Challenges in using the MPC algorithm

Model complexity: Building an accurate model of the process requires time and effort.

Computational calculations: MPC requires a large amount of calculations, which can make its application to high-dimensional systems difficult.

Delay: The presence of measurement and control delays can affect the performance of the algorithm..

2. Controlling the fluid level inside a water tank using MPC algorithm

Objective: To maintain the water level in a storage tank at a constant level, regardless of changes in the incoming or outgoing flow rate.
Basic elements of the system:
Tank: This is where the water is stored.
Inlet valve: Controls the amount of water entering the tank.
Outlet valve: Controls the amount of water extracted from the tank.
Water level sensor: Measures the water level in the tank continuously.
Controller: Contains an MPC algorithm that calculates signal values to control the two valves to maintain the target water level.

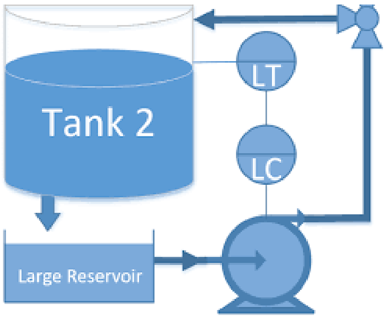

Fig1.shows controlling water level tank using MPC algorithm

Building the mathematical model

Building an accurate mathematical model is the first and most important step in applying a predictive control (MPC) algorithm to any system, including a reservoir water level control system. A mathematical model provides a quantitative description of the relationship between different system variables, allowing us to predict future system behaviour and make appropriate control decisions.
Matter Balance Model
The simplest model that can be used to describe the water level in a tank is the Matter Balance Model. According to this model, the rate of change of the volume of water in a tank is equal to the difference between the incoming flow rate and the outgoing flow rate.
We can express this mathematically as follows:
$dV/dt = Q_{in} - Q_{out}$
Where:
V: Volume of water in the tank
t: Time
Q_{in}: Incoming flow rate
Q_{out}: Outgoing flow rate
Converting the model to water level
Usually they are interested in the water level, not its volume. Assuming the cross-sectional area of the tank is constant (A), the relationship between the volume and the height (h) is:
$V = A * h$
Diverging the first equation with respect to time gives:
$A * dh/dt = Q_{in} - Q_{out}$
Hence:
$dh/dt = (Q_{in} - Q_{out}) / A$
This ordinary differential equation describes the change in the water level in the tank over time.
Importance of an accurate model
Prediction accuracy: The closer the model is to reality, the better the algorithm can predict the future behavior of the system.
Control performance: The performance of the MPC algorithm depends largely on the accuracy of the model. An inaccurate model may lead to incorrect control decisions and deterioration of system performance.
Building a mathematical model to relate the water level in the tank to the incoming and outgoing water flows

Converting the Water Level Model to State Space Form

To apply the MPC algorithm to the water level system, we must first convert the mathematical model we have obtained into what is called the "state space form". This form is a unified mathematical representation of dynamic systems and is widely used in the analysis and design of control systems.
State Space Form
The state space form represents the dynamic system as a set of first-order differential equations. In general, this equation can be written as follows:
$\dot{x} = Ax + Bu$

$y = Cx$
Where:
x: System state vector (e.g. water level and its rate of change)
u: Input vector (e.g. incoming water flow)
y: Output vector (e.g. measured water level)
A, B, C: Constant matrices that define the dynamics of the system
Transforming the water level model
Back to our model:
dh/dt = (Q_in - Q_out) / A
We can rewrite this equation as follows:
$\dot{x} = (1/A) * u$
$y = x$
Where:
x = h: Water level (system state)
u = Q_in - Q_out: Net flow (system input)
y = h: Measured water level (system output)
System matrices:
A = 0 (since there are no terms involving x in the equation)
B = 1/A
C = 1

3. Conclusion :

MPC algorithm is a powerful tool for achieving precise fluid level control in many industrial applications. By understanding the basic principles of MPC and applying them correctly, the efficiency of industrial processes can be improved and the quality of the final product can be increased. In this paper, we design a simulation of a water tank level control model using MPC algorithm. We build a mathematical model to relate the water level in the tank to the incoming and outgoing water flows, and then convert the water level model into a state space form, which is the first and fundamental step in applying the MPC algorithm. This form provides a unified mathematical representation of the system, which facilitates the application of advanced control algorithms. By applying MPC, precise and stable control of the water level in the tank can be achieved.

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