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Sturdy Model Predictive Control for Satellite Attitude Control System Using MRAS

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Abstract*: The author proposes an enhanced robust model predictive controller (RMPC) which is founded on a model reference adaptive system (MRAS). The MRAS technique allows building a RMPC controller using combinational methods for three-degree-of-freedom satellites that handles external disturbances and moment of inertia uncertainty to preserve the stability and performance of the closed-loop system. The derivation of the state feedback control rule requires solving a convex optimization problem subject to multiple linear matrix inequalities (LMIs). An Input constraint functions as an LMI within the mentioned optimization framework to protect actuator saturation. Through the MRAS method all disturbances present in the system input become obsolete. By implementing this algorithm operators gain several advantages because it maintains stability under uncertain model conditions while collecting exact system information. The proposed method delivers system simulation results which demonstrate improvements compared to those obtained from generalized Incremental Model Predictive Control (GIPC). The suggestive controller achieves superior robustness when compared to the GIPC approach according to the experimental results.*

Keywords*: Inequality of linear matrices, Reference adaptive system model, Satellite attitude control system, Robust model predictive control*

I. Introduction

Model predictive control (MPC) emerged as a highly sought-after method for use across complex multivariable as well as limited systems. This controlling approach exhibits many advantages yet the system performance does not fulfill expectations when encountering uncertainties primarily because prediction controllers lack explicit uncertainty evaluation. Scientific research has extensively focused on model predictive control robustness since the year 1990. The paper in [1] presents an RMPC controller for uncertain linear systems through implementation of dynamic state-feedback control law[9]. The processor demands remain very high for this algorithm to function. An offline implementation of RMPC controller is explained in [2] for systems with norm-bounded and polytopic uncertainties which uses output feedback control. A broader off-line RMPC controller for uncertain nonlinear systems is designed in [3].

II. MRAS Based Robust Model Predictive Control

The substantial reduction of internet computational load that results from offline RMPC methods comes at the cost of markedly reduced optimal performance compared to online RMPC. The paper [4] develops an off-line RMPC controller for linear systems affected by measurement noise and bounded state disturbance when both noise and disturbance lie within convex sets. Actual implementations of these algorithms appear in [5] and [6] within process control applications. The controller design through RMPC methods provides methods to minimize an infinite horizon objective function across different uncertain models. A solution to this problem emerges through setting an upper limit on the objective function and performing minimization over LMIs that guarantee robust system operation. The control methodology produces either state-based feedback or output-based feedback laws. The input limitations for actuator saturation prevention are embedded as LMI into the optimization problem by utilizing invariant ellipsoids during formulation. In spite of previous coverage, the author deals with disruption in another work.

The current work addresses this problem by implementing RMPC with MRAS. Research on model predictive control has spread throughout many industrial fields during the previous two decades including its extensive application in aerospace systems. A predictive controller operates as the guiding force which regulates the spacecraft towards its target spaceship according to information in [7]. Launch vehicles deliver so much shaking to satellites during their launch because of the resulting vibrations. The paper [8] uses model predictive control to isolate the entire satellite against vibrations. The designed control system regulates satellite attitudes using an explicit MPC implementation. The research establishes a combined three-axis RMPC controller for satellite attitude control systems which operates under constraint limits and exterior disturbances and uncertainty in inertia using MRAS together with online RMPC regulation[9].

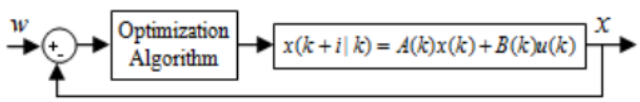

Fig 1: Block diagram of the RMPC method

A state feedback control law typically lacks the ability to reject disturbances that exist in the system. The current research addresses this problem through an online implementation of MRAS. The intended system performance gets defined through a reference model within the MRAS algorithm framework. The adaptive system performs estimation of the input disturbance while the system output error enables adjustments to the controller value. The successful implementation of MRAS requires developing the adjustment procedure to establish both system stability and complete elimination of mentioned error.

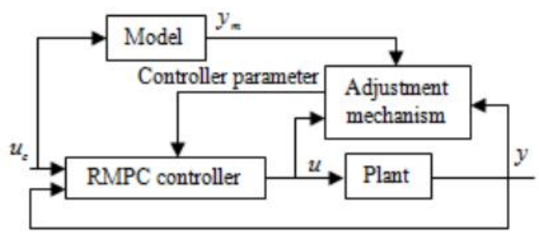

Fig 2: Block diagram of the RMPC method based on MRAS algorithm

III. Controller Performance

The step response and control effort of ACS for the linear model utilizing the RMPC and GIPC methods without constraints are shown in Figures 3.a and 3.b.

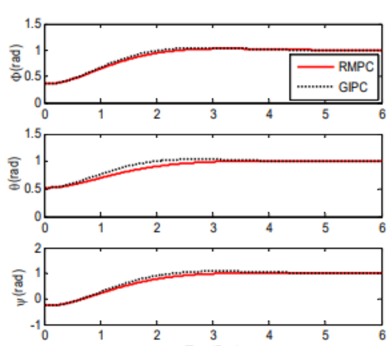

Fig 3a: Euler angles comparison of RMPC and GIPC algorithms without constraint

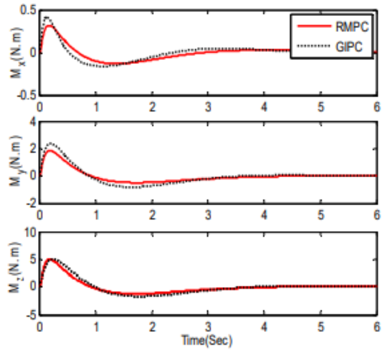

Fig 3b: Comparison of control actions between the GIPC and RMPC algorithms without limitations

The robustness analysis made it necessary to exclude control constraint considerations in the previous subsection. The input constraint becomes an explicit consideration point in the controller design process optimization problem. The control action remains within | u | <1 under these conditions. According to Figures 4.a and 4.b system stability continues while controllers generate decreased attitude control signals because an input restriction minimizes overshoot effects.

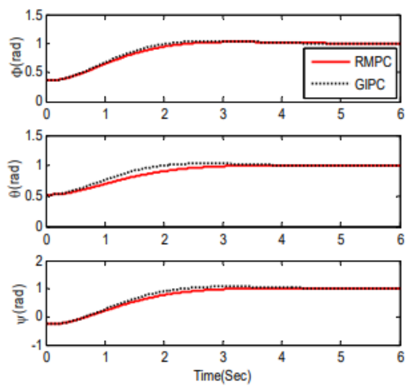

Fig 4a: Comparison of Euler angles between RMPC and GIPC methods when constraints are present

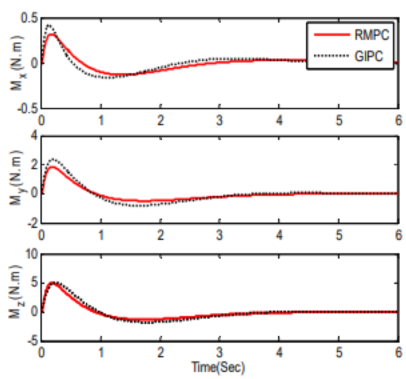

Fig 4b: Comparison of control actions between the GIPC and RMPC algorithms when constraints are present

The control behavior of the ACS linear and nonlinear models produces distinct operational results. The plots in Figures 5 and 6 demonstrate the step response behavior alongside control effort for both RMPC as well as GIPC algorithms. Simulation data proves that the RMPC algorithm generates more smooth control torques as compared to the GIPC method[9].

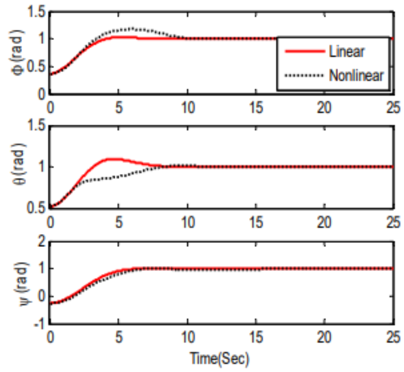

Fig 5a: Using the RMPC approach to compare the ACS step response for the linear and nonlinear models

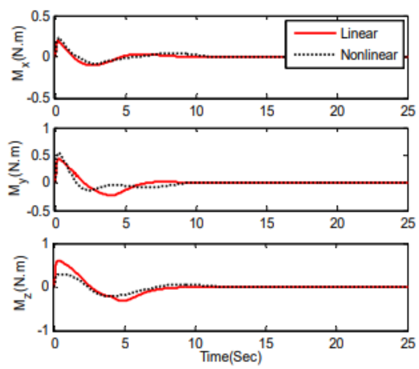

Fig 5b: Using the RMPC approach to compare the ACS control actions for the linear and nonlinear models

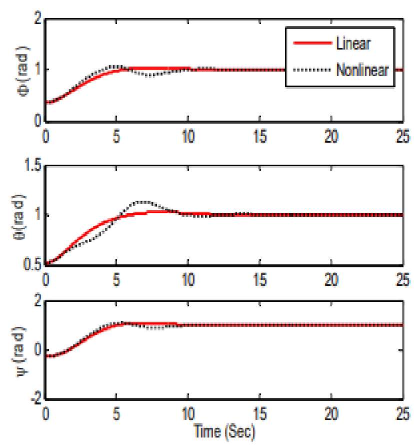

Fig 6a: Using the GIPC approach to compare the ACS step response for the linear and nonlinear models

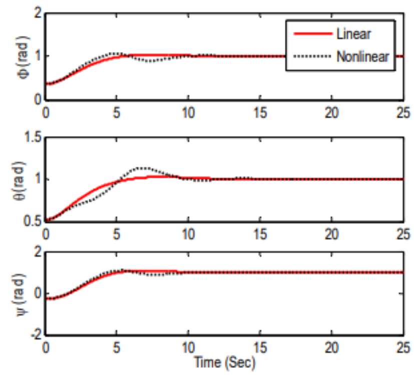

Fig 6b: Using the RMPC approach to compare the ACS control actions for the linear and nonlinear models

Subsection C from the preceding section presents the MRAS algorithm included within RMPC to address this issue. The Figure 7 shows the block diagram for combinational RMPC. The non-linear ACS model responds to a step input using the combinational RMPC control method as illustrated in Figure 8 which also demonstrates the associated control efforts. The introduction of outside interferences results in a complete elimination of their effects on Euler angle measurements and control actions.

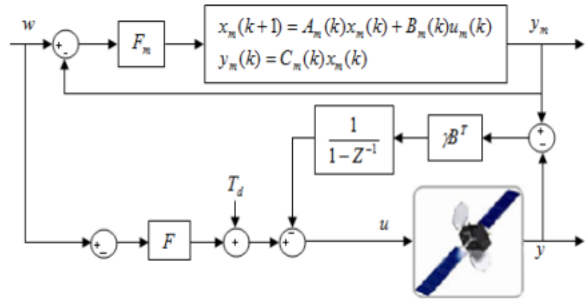

Fig 7: The block diagram of combinational RMPC

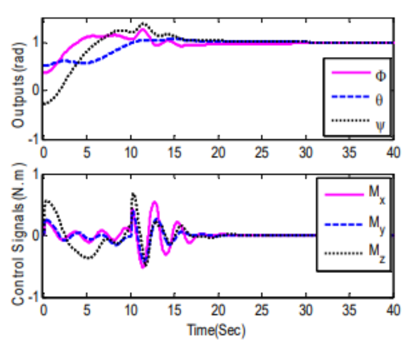

Fig 8: The performance of the combinational RMPC against nonlinearity

IV. Conclusion

The study implements a three-axis combinational RMPC controller for the ACS system to make the closed loop system more resistant towards input constraints and external disturbances and moment of inertia uncertainty. A state feedback control system maintains its stability through convex optimization problem solutions that produce multiple LMIs. The designed LMIs receive additional constraints which protect against response wheel saturation conditions. Disturbance attenuation of the RMPC method becomes accessible when incorporating the MRAS algorithm into the same system. The researchers tested the proposed controller through extensive simulations run on ACS' nonlinear model. Tests carried out in this work show that RMPC maintains strong stability under undisturbed conditions yet loses its ability to stabilize the loop when disturbances appear. The proposed work advances RMPC through MRAS because of its improved robustness capabilities. The proposed RMPC controller outperforms the combinational RMPC and GIPC controllers in managing disturbance and uncertainty parameters although they both display good performance against those parameters. The robustness performance of the combinational RMPC exceeds that of the GIPC.

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