# Design of Fuzzy Based Attitude Controller for a Spin Stabilized Micro-Satellite

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*Abstract:* - The objective of this paper is to develop an intelligent fuzzy attitude control strategy for detumbling with initial spin-up phase and spin rate control for small, low earth orbit satellite using only magnetometer and torquer. A magnetic moment produced by coils placed on the satellite will produce a resultant torque by interaction with the geomagnetic field, which may be used for attitude control purposes. Nevertheless, this simple, low power consumption approach poses several interesting control difficulties as the geomagnetic field viewed by a satellite, changes along its orbit. Besides this time dependency, this problem's mathematical description is highly non-linear, and hence a new intuitive control strategy is needed to solve the attitude and control demands of such a satellite. In this work, controllers are designed which, consists of Multi Input Multi Output (MIMO) fuzzy logic controllers. Also Single Input Single Output controllers are used to control the spin rate. This fuzzy control approach ensures the required performance in the presence of disturbance, uncertainty and various non-linearities and also describes the design of rule based fuzzy logic controller. This structure of the controller takes advantage of classical controllers while maintaining a significant degree of robustness, performance and portability. Furthermore, Simulation studies are illustrated for such control scheme.

*Key-Words:* - Fuzzy controller, attitude control, Detumbling, Initial Spin up, Spin rate control, magnetic control.

## 1 Introduction

A simple and low cost means of controlling the attitude of a small, low earth orbit satellite makes use of magneto-torquing technique. Magnetic coils around the satellite's XYZ axes can be fed with a constant current-switched in 2 directions, to generate a magnetic dipole moment M. This magnetic moment will interact with the geomagnetic field vector B to generate a torque N by taking the cross product:

$$N = M \text{ x } B \qquad (1)$$

The magnetic vector components within the XYZ axes can be measured in flight with in an onboard magnetometer. With that knowledge, control torque is applied to reduce the transverse rates, while keep spinning the satellite about it spin axis.

As soon as satellite is ejected from launch vehicle, entire body of the satellite starts tumbling. Since this is not a desired feature for a spin-stabilized satellite, in which there is only a spin rate

does exist with no transverse rates. In the detumbling mode, all the rates are made to die. However spin satellites are maintained with constant spin rate along maximum moment of inertia axis in order to make it stable. Initial spin-up is done along with detumbling mode in order to reduce the time taken for satellite to attain its stable position in the orbit. In this work, x axis is considered as satellites spin axis, while y,z are transverse axes.

The dynamic equations of rigid satellite can be linearised and uncoupled as:

Transverse rates:

$$\acute{\omega}_x = ((i_y - i_z) * \omega_y * \omega_z + N_x)/i_x \qquad (2)$$

$$\acute{\omega}_y = ((i_z - i_x) * \omega x * \omega_z + N_y)/_{iy} \qquad (3)$$

Spin rate:

$$\acute{\omega}_z = ((i_x - i_y) * \omega_x * \omega_y + N_z)/_{iz} \qquad (4)$$

Where
$i_x, i_y$=Transverse moment of inertia(X and Y axes)
$i_z$ =Spin axis moment of inertia
$\omega_x, \omega_y, \omega_z$=Rates along XYZ axes respectively.
$N_x, N_y, N_z$= Control Torques along XYZ axes respectively.

When magneto torquing is used as a means of controlling the attitude of satellite, the control torques for spin and transverse rates can be obtained from (1)

$$Nx = MyBz - MzBy \qquad (5)$$

$$Ny = MzBx - MxBz \qquad (6)$$

$$Nz = MxBy - MyBx \qquad (7)$$

In detumbling mode, only spin axis torquer is used to damp out all the transverse rates, while transverse torquers are used simultaneously to spin-up the satellite along its spin axis.

## 2 Fuzzy Controller

Fuzzy control is one of the expanding application fields of fuzzy set theory. Fuzzy controllers differ from classical math-model controller. Fuzzy controllers do not require a mathematical model of how control outputs functionally depend on control inputs and therefore especially suited for situations where the plant is too complex to model. Fuzzy controllers also differ in the type of uncertainty they represent it. In this application the presence of control constraints renders most traditional mathematical controllers impractical.
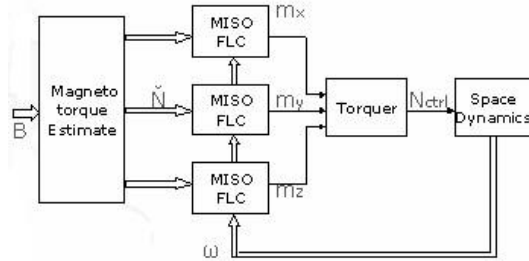
### 2.1 Detumbling and Initial Spin-up



Fig.1:Block diagram of the fuzzy Controller.

The input variables for the fuzzy controllers are the measured state variables of the satellite and the estimated control torques. This choice of input variables will make it possible to regulate the state variables while considering the control torque constraints. The torques can be estimated using (5) to (7) and the magnetometer readings.

The intention of this controller design was to define a set of control rules and to implement them in such a way as to make boundaries between them less strict, resulting in a system that cover a large universe of discourse with a relatively small rule base. A block diagram of the proposed fuzzy controller is shown in Fig 1. The controller consists actually of three fuzzy control laws. One for each magneto-torquer (Mx, My, andMz coils). Each control law embodies a fuzzy rule base to decide on the control desirability and output level when using the corresponding torquer.A total of six inputs were used:
$X_1 = \omega_x$ ,angular rate about x axis.
$X_2 = \omega_y$ ,angular rate about y axis.
$X_3 = k$ $(\omega_{z-}, \omega_{spin})$,Rate error.
$X_4 = Nx$, estimated control torque about x axis.
$X_5 = Ny$, estimated control torque about y axis.
$X_6 = Nz$, estimated control torque about z axis.

These variables are then mapped into fuzzy sets (ex. for positive for negative). The fuzzy set values are obtained from membership functions e.g.:

$X_1 \rightarrow m_P(X_1)$ and $X_4 \rightarrow m_N(X_4)$

then act accordingly to choose the torquer polarity. The membership functions for each input variable are shown in Fig 2,3,4 respectively. The reason for choosing the functions in this specific format are a need to limit the number of fuzzy sets and still obtain a linear mapping in the normal operating region of the system.
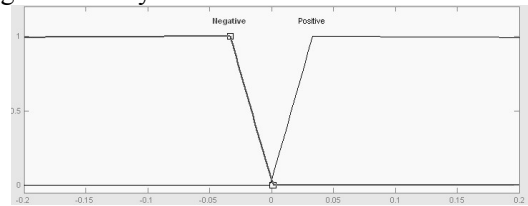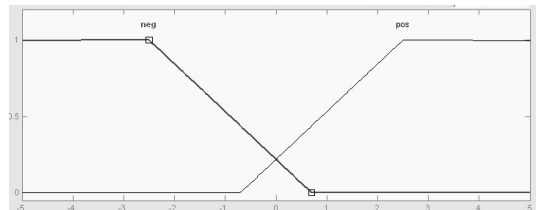


Fig.2: Membership function for variable $X_1$ ,$X_2$ ,$X_3$.



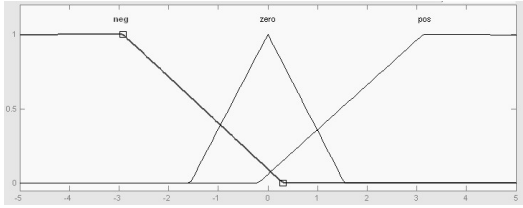Fig.3: Membership function for variable $X_4$ ,$X_5$.

Fig.4: Membership function for variable $X_6$.

The amount of overlap between the different fuzzy sets was optimised through simulation. The saturation point of each input variable was set using an engineering knowledge of the system and optimised using simulation trails.

In the detumbling mode both the transverse rates and estimated control torques are given as a input to Mz controller. A set of intuitive rules is used to describe the Mz controller. While in the initial spin-up mode the polarity of the constant current that is passed to Mx,My coils are solely determined from the sign and magnitude of the transverse earth's magnetic field component.

| Rule | $X_1$ | $X_2$ | $X_4$ | $X_5$ | U |
|------|-------|-------|-------|-------|-----|
| $R^1$ | P | - | P | - | - 1 |
| $R^2$ | P | - | N | - | + 1 |
| $R^3$ | N | - | P | - | + 1 |
| $R^4$ | N | - | N | - | - 1 |
| $R^5$ | - | P | - | P | - 1 |
| $R^6$ | - | P | - | N | + 1 |
| $R^7$ | - | N | - | P | + 1 |
| $R^8$ | - | N | - | N | - 1 |

Table 1: Mz Fuzzy variable control rule

| Rule | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | U |
|------|-------|-------|-------|-------|-------|-------|-----|
| $R^1$ | P | - | - | P | - | Z | - 1 |
| $R^2$ | P | - | - | N | - | Z | + 1 |
| $R^3$ | N | - | - | P | - | Z | + 1 |
| $R^4$ | N | - | - | N | - | Z | - 1 |
| $R^5$ | - | P | - | - | P | Z | - 1 |
| $R^6$ | - | P | - | - | N | Z | + 1 |
| $R^7$ | - | N | - | - | P | Z | + 1 |
| $R^8$ | - | N | - | - | N | Z | - 1 |
| $R^9$ | - | - | P | - | - | P | + 1 |
| $R^{10}$ | - | - | P | - | - | N | - 1 |
| $R^{11}$ | - | - | N | - | - | P | - 1 |
| $R^{12}$ | - | - | N | - | - | N | + 1 |

Table 2: Mx,My Fuzzy variable control rule

As stated in [Steyn] work rules evaluation is performed using correlation-product encoding, i.e

the conjunctive (AND) combination of the antecedent fuzzy sets. for example rule 1:

$$R^1: \mu^1 = m_P(X_1).m_P(X_2).m_Z(X_3)$$

where $mi$ are the membership functions, the truth value obtained is then used to scale the output:

$$R^1: y^1 = \mu^1.U$$

when the result of all the rules is known the final value is obtained by disjunctively (OR) combining the rules values:

$$y = \sqrt{(y^i)} = \text{sgn}(\sum_{i=1}^{N} y^i) \ \min(1,|\sum_{i=1}^{N} y^i|) \quad (6)$$

The disjunction method of (6) can be described as a kind of signed Lukasiewicz OR logic. It is chosen to maximally negatively correlate the rule outputs. For example, opposing rule outputs (different in sign) cancel each other to deliver a small rule base output.

## 2.2 Spin Rate control

The spin rate control is done to keep the satellite spinning at constant rate, even when there is a distubance. Fuzzy spin rate controller basically consists of two Single Input Single Output (SISO) controllers. Spin rate control involves in two modes, either spinning up or spinning down.
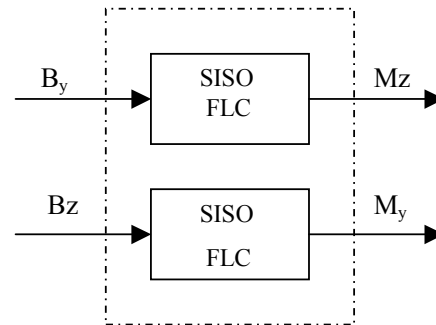


Fig.5:Block diagram of spin rate controller.

The input variables for this fuzzy controller are transverse component of earth's magnetic field By and Bz respectively. For increasing the rate, fuzzy logic controller gives the same sign as its input magnetic field for My controller, while the polarity given by Mz controller is directly opposite to its input magnetic field sign.

For spin up, the rules are
    If Bz is negative then My is negative
    If Bz is positive then My is positive.
Also for Mz controller
    If By is negative then Mz is positive
    If By is positive then Mz is negative

Similarly for spinning down the rules are slightly modified. In this Mz controller follows the same sign as it input magnetic field does, while other follows opposite to that of input. Rules evaluation is performed using correlation product encoding.i.e conjunctive (AND) combination of the antecedent fuzzy sets. The membership function for input variable is shown in fig.6.Since the overlapping is made much minimum to sharply define a boundary for the polarity that could be applied to torquers.
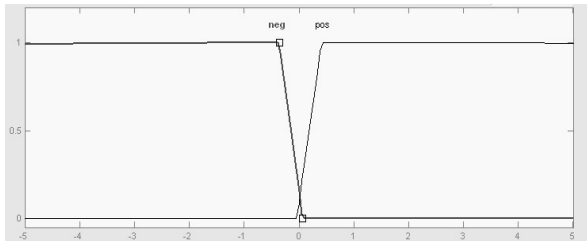


Fig.6: Membership Function for variables Bx,By

# 3   Simulation Results

To evaluate the performance of the proposed fuzzy controller a through simulation program was developed. Also a small amount of disturbance is also added while simulation, which still shows the performance of the fuzzy controller.

Satellite Configuration
$I_x = 1.442010$ Kg-m$^2$
$I_y = 1.338694$Kg-m$^2$
$I_z = 1.255427$Kg-m$^2$
Initial Rates
$\omega_x = 6$ deg/sec
$\omega_y = 6$ deg/sec
$\omega_z = 6$ deg/sec

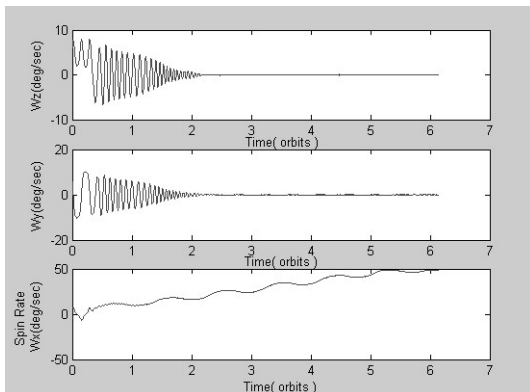## 3.1   Detumbling and Initial Spin up



Fig.7:Detumbling with initial spin up Fuzzy controller response

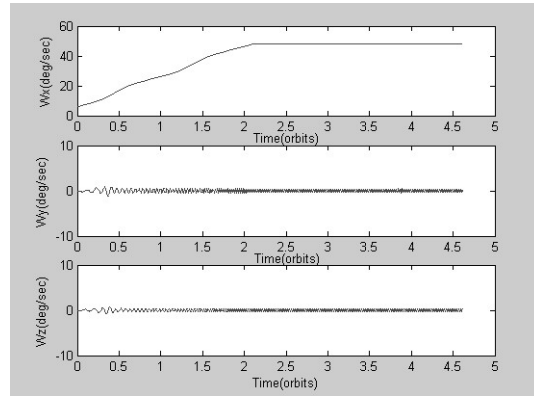## 3.2   Spin Up Response



Fig.8:Spin Rate Controller Response-spin up
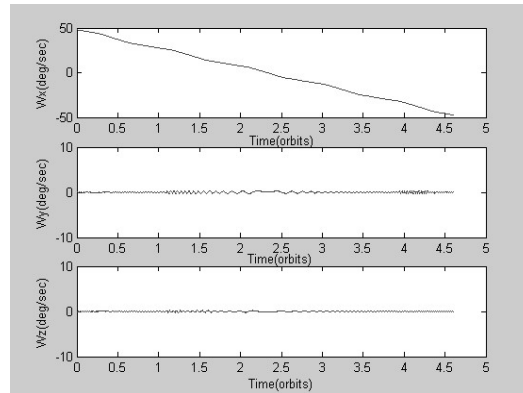
## 3.3   Spin Down Response



Fig.9: Spin Rate Controller Response-spin down

# 4   Conclusion

A rule based fuzzy controller was presented for detumbling with initial spin-up phase and spin rate control fro a spin satellite. This fuzzy controller perhaps performs better with non-linearities and uncertainity,an extension of adaptive fuzzy controller is being explored to enhance the behavior of attitude control system in an uncertain environment.

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