Proceedings of the International Conference on Man-Machine Systems (ICoMMS)
11 – 13 October 2009, Batu Ferringhi, Penang, MALAYSIA

Development of Attitude Control System on RCM3400 Microcontroller for Nano-Satellite Applications

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Abstract- **This paper describes the development of a nano-satellite attitude control system (ACS) which employ a Kalman filter based controller and a simple adaptive predictive fuzzy logic controller (APFLC) for a 1, 2 and 3 axis orientation using RCM3400 microcontroller. This paper presents the performance comparison of the APFLC and Kalman filter based controller implemented in the hardware. The physical interface module, configuration with several key features, communication protocol and data handling for the micro-controller are also described.**

I. INTRODUCTION

The satellite maneuvered through the orbit with the use of the ACS to stay on course and always pointing to the earth reference so that the solar cell will keep facing the sun and camera to the earth, this is possible by hardware and software embedded in the satellite that continuously control and adjust for better control performance. The ACS operates as a one-axis, two-axis, and three-axis attitude stabilized control system. Attitude control algorithms software for ACS is part of the attitude determination and control subsystem payload (ADCS) stabilizes the satellite and reorients it to desired directions during the flight, while countering with the external disturbance torques acting on it. This requires that the satellite determines its attitude using sensors and control it using actuators. Attitude that we refer to is rotation of the satellite body frame for satellite movement in space refer to [1-2], the movement are monitor in data of x-axis (roll), y-axis (yaw) and z-axis (pitch) and these data are the main character to evaluate the movement and orientations of the satellite in space.

The used of geomagnetic field into ACS is not new and from research done by N.Mohd Suhadis and R.varatharajoo ,Mark L.psiaki [3-5].it is said that the electrical current flowing in the ionized upper atmosphere and the conduction by currents flowing in the earth's crust generate the magnetic field, the magnetic dipole moment within the satellite generates torque that can be use to control the satellite's attitude this method are widely used because its low power consumption ,lightweight and extremely inexpensive compare to other
methods of control [6][8].other than the geomagnetic field they are other method of determination, the direct measurement using a gyros [7],but gyros are expensive and failure-prone, not to mention the significant mass and power that the gyros sensor consume.
Some method that use the direct vector attitude rate data with either deterministic, differentiation techniques or apply filter such as kalman filtering method to estimate attitude rate [6, 9-10]. Another method uses full 3-axis attitude estimates as input to rate estimation filter [11], and robust PID control for attitude tracking in large angel control subjected to nonlinear coupling and uncertainties, PID work well for first and second order system but with long delay with harmonic and uncertainties disturbances a more sophisticated controller is needed [12].although the nonlinear H_∞ is the more comment method for a nonlinear robust controller, the solution to associated the Hamilton-Jacobi equation is extremely complicated and resulting to a complex and not easy implement system[13]. This paper consist of 3 part, starting with description on model and development of the Adaptive Predictive Fuzzy Logic Controller (APFLC) with model, part 2 experimental setup for hardware telemetry module configuration done, part 3 describe the system implementation, and result. From the simulated result that was done with the propose method and setup the performance of the controller are evaluated and discuses in conclusion.

II. MOTIVATION TO THE WORK

The difficulty in this area is that it is new and the technology itself is not explored by many in the nation and expertise needed come from international past project. By seeking of such technology might open new reach and possibility of future study for others. The objective is to implement a controller algorithm developed inside the microcontroller board (RCM3400) with the external flash memory.

III. METHODOLOGY

The proposed simulator consists of five modules, namely, the Attitude Controller System (ACS), Actuator and Sensors, simulation or model of a satellite behavior, simulation of the motion of satellite movement, the analog to digital and digital to analog converter. As shown in Figure 1,

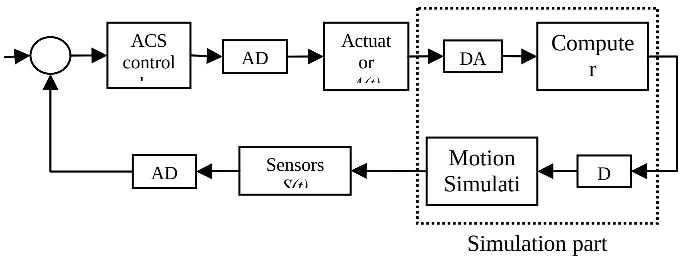


Fig. 1. Simulator Block Diagram.

To apply the system as in Figure 1, a setup as in Figure 2 is set. In this setup, the Personal Computer is used to act as an interface between the microprocessor and the On Board Computer (OBC).

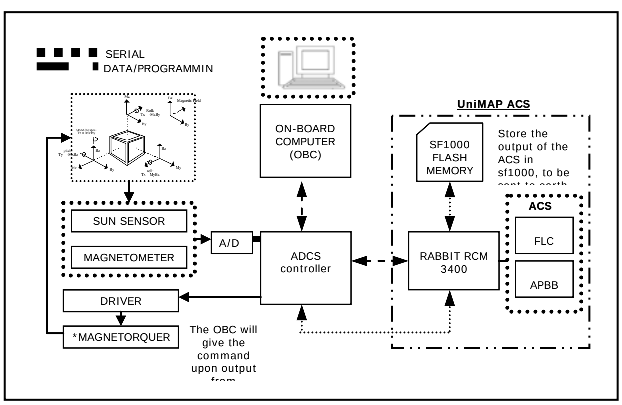


Fig. 2. System block diagram

i. Setup for Hardware

The setups are set with the actual telemetry that is going to be used in the actual satellite system, with serial protocol data transmission and baud rate. The software development, in this project includes initialization of hardware port and library function, hardware and software development and verification. Due to the limitation in internal memory of the processor which is 512Kbyte flash memory, RCM3400 needs external memory allocation and that is done via Serial peripheral interface (SPI), SPI is one of the common type of UART serial protocol used, where the RCM3400 processor are set as master, that control the serial clock (SCLK), and chip select (CS/SS) of the communication that was used to communicate the main processor (RCM3400) with the external memory, SF1000. The connections of the hardware are shown in Table 1.

TABLE 1
PIN CONNECTION BETWEEN SF1000 AND RCM3400

Pin's Connections:	
SF1000	*RCM3400*
1	PC7 / MOSI
2	GND
3	PB1 / SCLK
4	3.3V
6	PC6 / MISO
8	Status / SS / CS

ii. Memory Management

The processor has 2 type of memory, Flash and SRAM, see Figure 3. When doing embedded programming there are 2 things to be consider, the first one are the memory and second are the computations speed, first the memory.

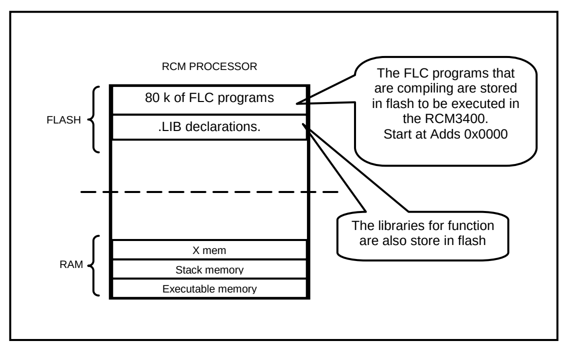


Fig. 3. Microprocessor memory management

The programs is saved in the flash section of the memory with the library used in the programming, this is because instruction call in FLASH are faster to execute compare to the SRAM. This complies with the second rule of thumb mention earlier. The second advantages of putting the programs in the FLASH, for it will not be lost when the power are cut off to the processor. Even so, we still used the SRAM to allocate the accumulated and recursive data that are used for update and calculation of the controller. the SF1000 external flash memory which have 8MB of flash memory space is used as it is space qualified and data won't be lost even when the power are off. The mapping for the SF1000 is shown in Figure 4 and table 2.

TABLE 2
DATA AND MEMORY ALLOCATION

data	**Byte**	**Start address**	**End address**
Input for ***ROLL***	4 x 13562= 54248	20000000	2059999
Input for ***PITCH***	4 x 13562= 54248	2060000	2119999
Input for ***YAW***	4 x 13562= 54248	2120000	2179999

The method used for writing to the external flash memory is a direct writing style, where we specified the address of which memory cell we want to write or read beforehand. For the *SF1000* flash memory, we will have around 8 million memory cell address to write to.
From Figure 5, we isolate and partition the memory of interest by memory address and store all the data output to this memory section.

The system outputs are saved in each section of the allocated address as in Table 2. These addresses are changeable in the programs and depend on the data type. For this work, data type is in float (4byte) and the iteration is 13562 data from a satellite tool kit's (STK) simulation data.

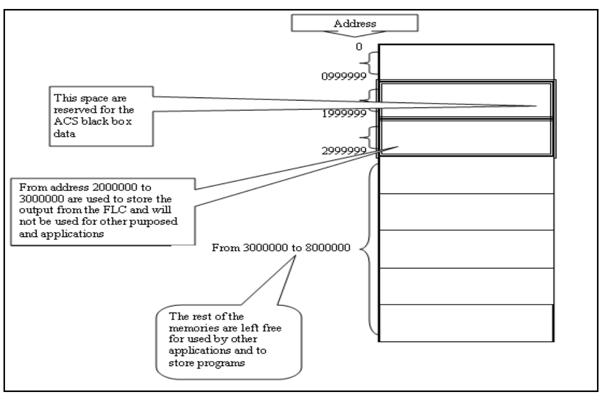


Fig. 4. SF1000 Memory mapping

iii. Controller system design

Altitude controller system, are the body of the work itself and it is subjected to use several type of it for comparison that is the main purpose of the simulation, to test the behavior of the satellite with different type of controller method. The controllers that are used in this work are an adaptive predictive fuzzy logic (APFLC) [11] taken from the past ACS work. A Kalman Filter (KF) [9] and the basic PID controller also method of coupling is introduce to the controller for 2- axis ,and 3- axis altitude control system.

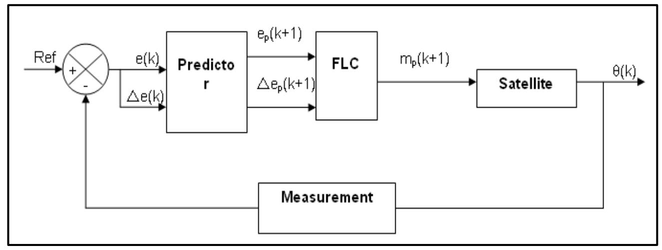


Fig. 5. APFLC block diagram

For the APFLC The predictive errors, $e_p(k+1)$ and $\Delta e_p(k+1)$,are computed as Current error $e(k) = \theta^*(k) - \theta(k)$, **(1.0)** with the Predicted attitude (linear prediction) $\theta p(k+1) = \theta(k) +\{ \theta(k) - \theta(k-1)\}$,**(1.1)** for the predicted error $e_p(k+1) = \{ \theta^*(k+1) - \theta p(k+1) \}$,**(1.2)** that need to be compare to the Predicted change in error $\Delta e_p(k+1) = e_p(k+1) - e(k)$, **(1.3)**

Meanwhile for the case of the kalman filter, linearizing dynamics and output functions at current estimate propagating an approximation of the conditional expectation and covariance, Witch mean that the EKF measurement update with linearize output function follow the equation 2.0,2.1 and 2.2 below

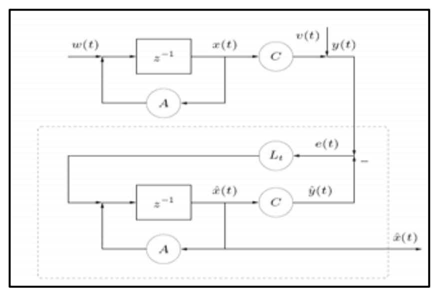


Fig. 6. EKF block diagram

$$x = \hat{x}(t/t-1), \quad \textbf{(2.0)}$$

$$\textbf{C}= \frac{\partial y}{\partial x}(\hat{x}(t/t-1),0) \quad \textbf{(2.1)}$$

$$\textbf{V}= \frac{\partial y}{\partial x}(\hat{x}(t/t-1),0)\Sigma\frac{\partial g}{\partial v}(\hat{x}(t/t-1),0)T \quad \textbf{(2.2)}$$

iv. Software

To run the control algorithm, a hardware initialization is required as to ensure the RCM3400 is fully operational. We must declare and initialize RCM3400 board, SPI for serial communication interface for communication with the external memory of SF1000, setting the baud rate for the RCM3400 transfer speed, in this setup we used 57600 baud rate, and for the library routines. We must ensure that all the initialization is done correctly so that the programs function well. If the initialization has error, it will cause the program not to function properly and the outcomes of the controller are not corrected and unusable. There were several process involves in our programming language such as board initialization, input data initialization, controller algorithm, store data and display data. As shown in Table 3.

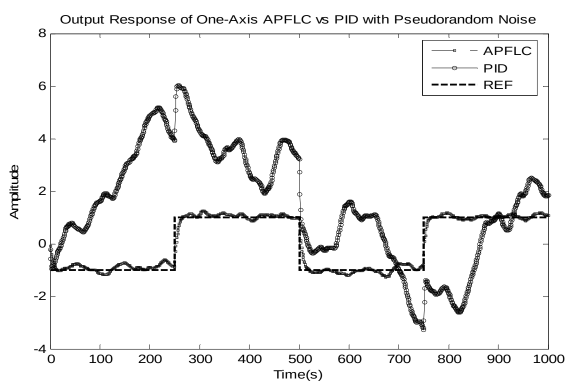
TABLE 3
. LIST OF DEFINE

Definition for Rabbit processor
#define DINBUFSIZE 15 #define DOUTBUFSIZE 255 #define seropen serDopen #define serputc serDputc #define serputs serDputs #define sergetc serDgetc #define BAUD 57600 #define SPI_SER_A #define SPI_CLK_DIVISOR 5 #define SHOW_ERROR 1 #define SERIAL_SINGLE_STEP 0 #use SF1000.lib #define BLOCKCOUNT 32

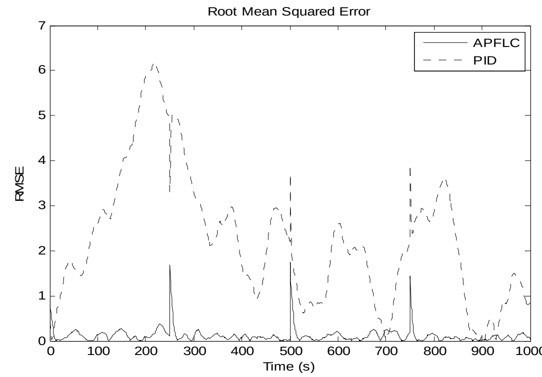
IV. SAMPLE AND RESULT

Sample of Kalman filter random input and noise compare with APBFLC and PID.

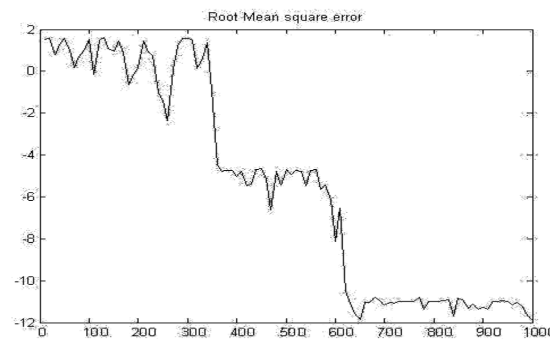
Fig. 7. below show the result for output from APFLC and PID with result of EKF



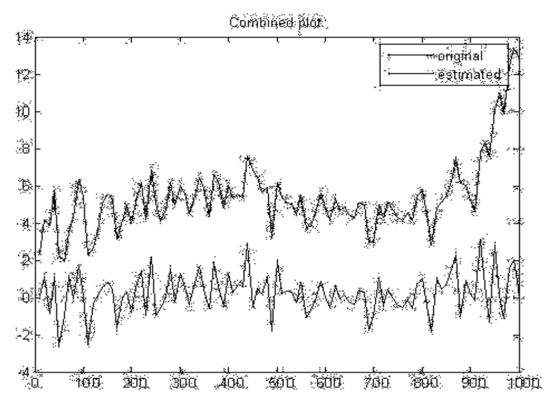
7. a) Result of APFLC and PID with noise



7. b) Root mean Square for APFLC and PID



7. c) Root mean Square for EKF



7 .d) Result for EKF with random input and noise

V. DISCUSSIONS AND CONCLUSION.

From both figure 7b and 7c observe that the root mean square error (RMSE) for the APFLC is the smallest follow by the EKF and PID, the reason for the small RMSE in APFLC is due to the APFLC is a intelligent type controller that response to the sudden changes in the system, it have an advantage of adaptive and predictive nature to the sudden nature of the system, having faster algorithm respond to changes in the system while the EKF only use an estimated value as a predictor for the next step output. it is propose to further improve the performances to obtain a smaller RMSE and make the controller more robust for nano-satellite application.

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