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Research paper

Stabilization of UAV using Delta Sigma Modulator based controller

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Abstract

The design development and control of Unmanned Aerial Vehicles (UAV's) have stimulated great significance in the automatic control research for the past 2 decades. In specific, Quad rotor systems are a promising platform in the area of Uthe AV research, due to its simple in construction, maintenance, ability to hover, and their vertical takeoff and landing (VTOL) capability. The dynamics and control of quad rotor are highly nonlinear and under actuated so it is considered as a test-rig to verify any new proposed nonlinear control algorithm. Different control algorithms were proposed and implemented to stabilize the UAV attitude, and altitude. Adaptive control and navigation algorithms also implemented in UAV platform to ensure the maneuvering against the internal and external disturbances. The proposed research paper explains the implementation of the developed digital control algorithm Delta-sigma modulatoan r (DSM) based controller for UAV to enhance the robustness.

Keywords:

Introduction

The unmanned aerial vehicles are used in multiple vehicle teams, mobile sensor networks, gathering the details for the various real-time applications like traffic monitoring, military applications, real-time data acquisition and much more the quad rotor UAV takes up the important role. Compared with existing helicopters, quad rotors are having simple in construction avoiding the complex mechanical lthe inkage stthe ructures which lessen the weight of the system.

Also, the individual four rotors are smaller in size compared with the main rotor on a helicopter which can also reduce the weight. The quad rotors can reach at different altitude levels in the closely clustered or dense environments. They have an Autopilot, so there is no need for a human pilot to control the aerial vehicle. The control of a quad rotor may be done by using radio frequency control from a ground station or automatic control these control strategies being studied by many researchers.

In [1], PID control is used in most of the places to control the robotics and even for industrial automation. The same scenario in UAV platform too. In [2], the PID controller used in the quad rotor for both its attitude and altitude control. It observed that it have better performance in pitch angle tracking. In [3], Position and orientation of a quad rotor regulated by the PID controller. Obtained performance shows good attitude stabilisation. After PID controller LQR controller also implemented in Quad rotor control. In [4], Runcharoon and Srichatrapimuk formulated an SMC based on Lyapunov stability theory. It's tracking feature was effective with injected noise which showed good robustness. In [5], Fang and Gao formulated integrator back stepping control by adding an integrator in the algorithm which increases the robustness of the general back stepping algorithm. In [6], Diao et al. a varying adaptive controller with continuous time in which unknown mass of uncertainties, aerodynamic damping with coefficient and moment of inertia exist. In [7], Palunko et al. an adaptive control scheme using feedback linearization with quadrotor used with energetic changes in centre of seriousness. In [8], flexible control system the controller based on rectilinear movements (L1)which are used to reduce the energy between robustness and control performance which able to afford a strict and favourable wind rush. In [9], Bai et.al.implemented a powerful controller for pitch, roll and yaw control system and this mechanism is based on compensation technique. In [10], Tony and Mackunisy deal by using powerful control algorithm to reduce the various environmental disturbances to the system. In [11], an optimal control algorithm implemented for tracking of both approach and direction which gives an effective performance. In [12], Falkenberg et.al. applied an optimization algorithm based on H∞ looping to a quad rotor but the result did not seem more efficient. In [13], Roza and Maggiore implemented linearization and input dynamic inversion to set a effective controller to take a control action in such a way that it is in terms to take an account of various parameters like attitude

angle of a system and path parameters. In [14] quad rotor, stabilisation was implemented by using a scheme of neural network of an adaptive system in the presence of a sinusoidal disturbance. In [15], a composite down covered system; to eliminate the chattering effect of the sliding mode control algorithm back stepping is used successfully. In [16], a fuzzy model based control is proposed. The simulation results show that it is better than the conventional discretization methods. In [17], a controller is designed using uncertainty and disturbance estimation. In[18], a wireless camera is used to obtain the status of UAV and provides feedback to a PD controller. The mechanism by which the DSM controller gives better results in that the cumulative error signal is always attempted to reduce to zero. In a general purpose delta-sigma modulator, the normal range of input signal is limited as .55 that is mean value of the output of a delta-sigma modulator throughout a sample period is almost equal to the analogue value of the input signal that is only whenever the normal input signal value is lesser than .55. The reason is the second integrator output gets saturated, i.e. exceeds the supply voltage, when the normalised input exceeds 0.55, In the proposed signal dependent DSM, signal-dependent feedback is used to minimise the integrator outputs.
In this paper, Signal dependant Delta-sigma modulator is proposed and is used as the controller for the UAV. The proposed technique reduces the deviation error to 0.001%. In Fig.4 is shown the basic schematic diagram of UAV in which the encircled portion is the proposed modification and in Fig.5 is shown the block diagram representation of autopilot with proposed DSM controller.

2. Proposed Technique

The IInd order, single bit quantizer with unity feedback gain delta-sigma modulator shown in the Fig. 1, and it is the general purpose delta-sigma modulator where the analogue input signal value is x. Thus the sample and hold circuit is used to sample the analogue signal with an equivalent sampling period and the clock period of delta-sigma modulator circuit T_C. D is the delay module which is used to provide one clock pulse delay of the delta-sigma modulator, and the quantizer module is Q with the output range of +1 or -1. Whenever the normal input signal of a single stage delta sigma modulator is greater than .55, then the system becomes unstable. Here x(i) is the analogue input signal and also sampled signal to the delta-sigma modulator circuit for the duration of the sample period of ith instant. The mean value of the quantizer during the period of kth instant and present period T_U ($T_{U>>}$ T_C) is denoted as y(k). The normal input signal to the delta-sigma modulator of kth instant and EX-NOR (k) is the mean value of the sampled value of the input to the feedback gain. For a classic delta-sigma modulator with unity feedback gain more than the unity feedback gain, y(k) is equal to EX-NOR (k) during the period of kth instant.

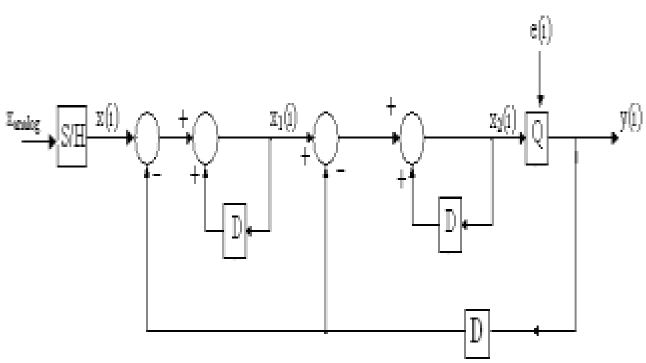

Fig.1: Conventional DSM

3. Proposed Block Diagram of DSM II

The proposed block diagram represents the delta-sigma modulator II is shown in Fig.2. The input signal is sampled by using the sample and hold circuit I, and at a sampling period, T_U and is denoted as $(x)T_U$ or simply by x. The input signal (xnor = x/n) which is normalised the range from -1 to +1 where n is feedback gain constant. The delta-sigma modulator act as an input signal which is given by analogue signal x. The input signal x is used to control the operating period of a delta-sigma modulator. The clock signal is used to operate the delta-sigma modulator with period T_C. The feedback gain is n|x| and the value of n taken higher than 1so as to satisfy the condition for stability. The input x should not be higher than the feedback gain because the gain component inserts in the feedback path. The gain of the feedback path will divide the average output value during each period. The effect of signal-dependent feedback gain compensated by the working time T_O of the DSM circuit. Therefore,

$$T_O = k \mid x \mid \tag{3.4}$$

Where k is the constant of proportionality. Substituting in equation (3.4) that when $\mid x \mid = \mid x_{\max} \mid$ =n, $T_O = T_U$ results in $k = \frac{T_U}{n}$.

Substituting the value of k in equation (3.4) which gives the value of TO as;

$$T_O = \frac{T_U \mid x \mid}{n} \tag{3.5}$$

TU and TC are selected such that TU>>TC. As in DSM1, x1, x2 and y are the average output value of first integrator, a second integrator, and quantizer respectively and the average quantizer value and error signal during the ith update period denote as e. The same notation is followed in other proposed DSMs also. During the operation of DSM, the output of single bit quantizer is +1 or -1, the SR flip-flop said when the positive signal is updated, and switches from s1 & s7 closed. The output of the DSM consist of pulses off range +1 and -1. The DSM output resolution, Δy is given by,

$$\Delta y = \frac{T_C}{T_U} n \tag{3.6}$$

Resolution Δy controls the operating period of DSM, such that operating period proportional to |x|. When the SR flip-flop set the value of Δy integrated. The switches from s1 to s7 are open when SR flip-flop is reset(phase Φoff), which makes the functioning of DSM stops and the output of the residual sampling period is zero, as the output of the quantizer clamped to an analog ground via switch s8.
The integrators I1, I2, and I3 reset to the value zero and combined addition of Δy. The resolution of Δy is taken such that it is less than |xmax| (n) in a sampling period. The DSM operating cycle repeated during the next positive transition.
Each block labelled as the time at which the states of different blocks updated. The bit stream at the output for the duration of each sampling period gives the digital presentation of the input signal. The output value of each bit stream of sampling period is (y) and proportional to analogue input signals. The proposed timing chart of DSM2 as shown in Fig.3.3. The DSM circuit operating time for each updated period will be in the range 0 ≤ TO ≤ TU. TU and TC are selected such that TU>>TC.
The proposed modulator xnorcan vary from -1 to +1 and is stable for the full range. When the DSM operated in low clock period with dc

input, the value of the digital output will be a good approximation of the input.

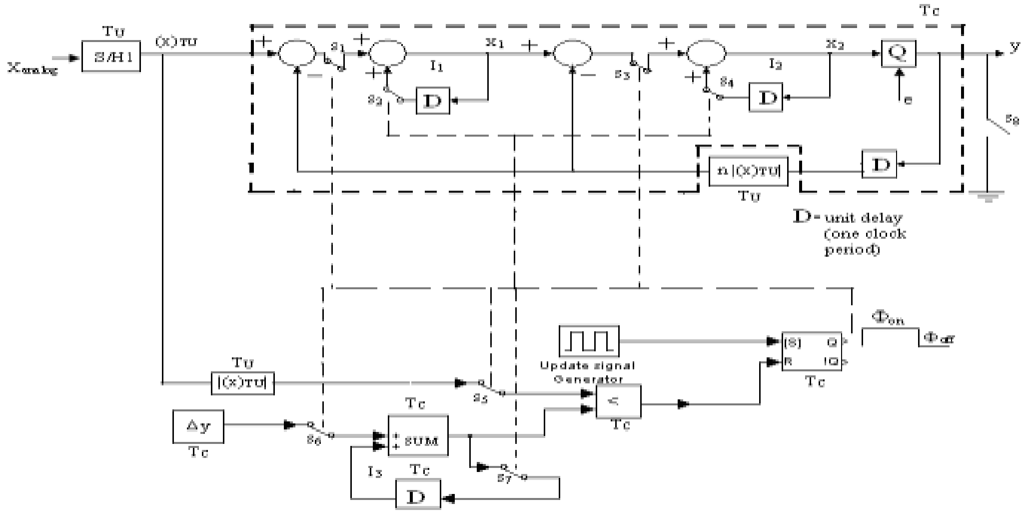

Fig. 2: Proposed DSM of Configuration 2 (DSM2).

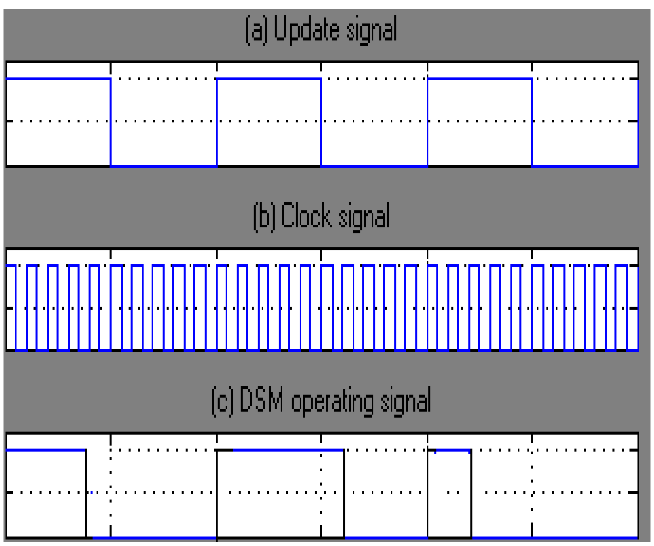

Fig.3: Timing Chart of Update Signal (Period TU), Clock Signal (Period TC) and DSM Operating Signal (Duty TO).

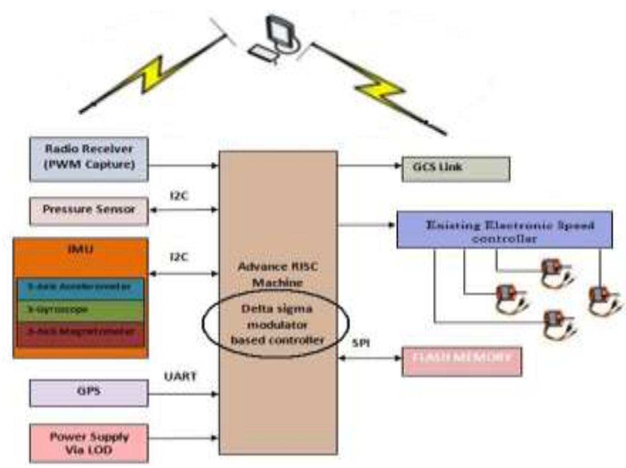

Fig.4: Autopilot with proposed modifications

In Fig.2, the roll rate controller, pitch rate controller and yaw rate controller of existing Autopilot (PID controllers) replaced by modified DSM based controllers. K' represents the gain matrix.

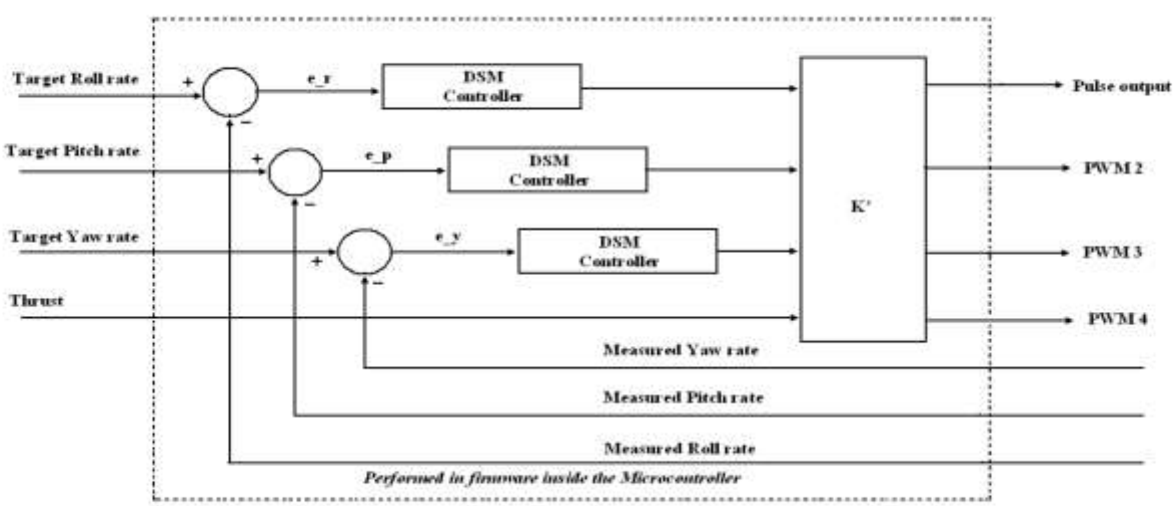

Fig.5: Autopilot with proposed DSM controller

Fixing the gain values of the PID controller is difficult. The attempt is always to optimise overshoot/undershoot, settling time, rise time and steady-state error. For dc signal, the DSM gives a far better accuracy of 0.001%. The conventional DSM has a limited range of input. If the normalised input is above 0.5, the DSM will become unstable. The proposed DSM can operate for the full range of input signal and never become unstable and retains the accuracy of 0.001% for dc signal.
The digital representation of the input signal is given by the output of the bit stream of the quantizer during each sampling period. The output of each sampling period of the bit stream is proportional to the sampled analogue value of the input signal. The DSM is stable for the complete range of input signal because of the upper bound of the stable variab
le never overloads the quantizer. In the overall range, SNR and PSD are more convenient and profitable than DSM.

4. Results and Discussion:

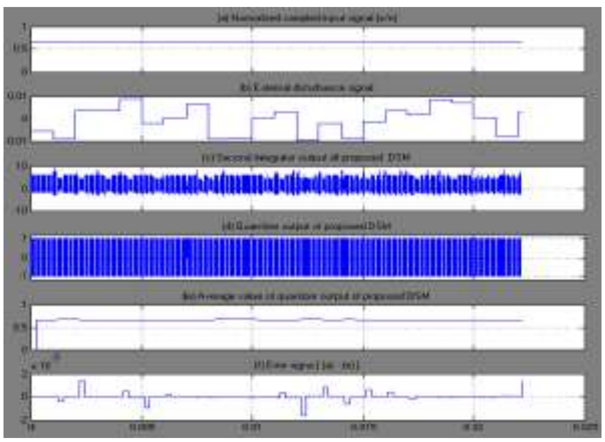

Fig.6: Simulation results with DSM controller

In this simulation, the altitude variations for a constant PWM signal from the remote controller with random external disturbances are studied. The constant PWM is converted to step input (0.67 V as an example) and as shown in Fig.6(a). The external random disturbance signal as shown in Fig.6(b) the second integrator output is shown in Fig.6(c) and is less than 10 V and so the operational amplifier which used for the integrator will never be saturated. In Fig.6(d) it is shown that the quantizer output of the DSM1 will generate a sequence of pulses of amplitude +1,-1.
There are no continuous ones or zeros (in the expanded view) which signifies instability. The instability of the circuit is due to inconsistency in the pulses.
Fig. 6(e) shows the output of DSM with the demodulated signal of the quantizer. The average value of pulses at the output of quantizer in each update cycle is known as a demodulated signal. The signal produces the demodulated signal is analogue input which corresponds to the PWM. In Fig. 6(f) it is shown that the maximum absolute value of the error is 0.15mV.

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