Embedded On-Board Control of a Quad rotor Aerial Vehicle

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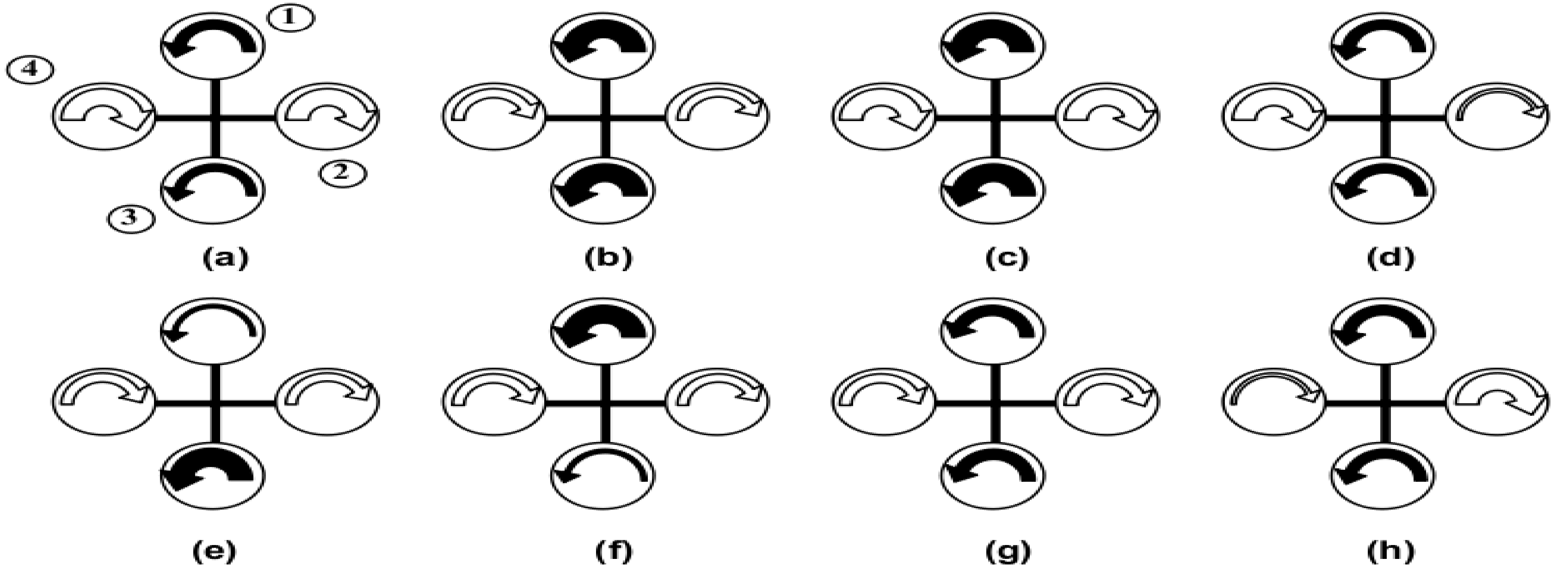
Quad Rotor Aerial Vehicle

- Inherent ability to hover in place while carrying small payloads.
- Requires high processing power for stable flight using four control loops.
- Fixed pitch rotors driven by electric motors provide the required thrust.

fig 1. Helicopter [1]

fig 1.1. Quad rotor [2]

Pilot – in – the – loop system



(a)	Yaw (anticlockwise direction)	**(e)**	Pitch (anticlockwise direction)
(b)	Yaw (clockwise direction)	**(f)**	Pitch (clockwise direction)
(c)	Take-off or take-up	**(g)**	Land or take-down
(d)	Roll (clockwise direction)	**(h)**	Roll (anticlockwise direction)

fig 2. Direction of each rotor [4]

- Two rotors spin in clockwise direction, Two other rotors in counter-clockwise direction.

Pilot – in – the – loop system

- The action of the structure
  - $T_T = T_N + T_S + T_E + T_W \quad (1)$
  - $T_R = l\,(T_W - T_E) \quad (2)$
  - $T_P = l\,(T_N - T_S) \quad (3)$
  - $T_y = K/\alpha\,(T_N + T_S - T_E - T_W) \quad (4)$

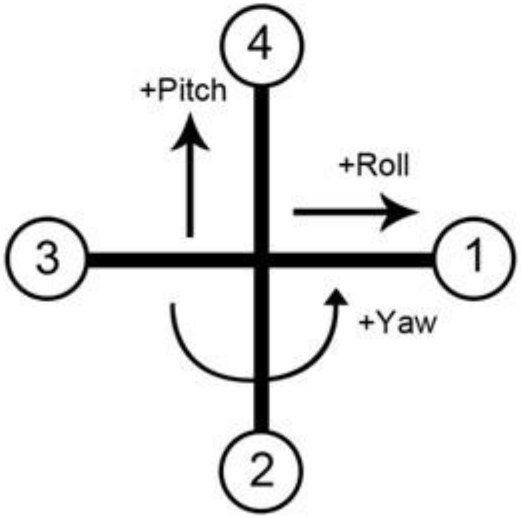


fig 3. Direction of axes [3]

where,

T_T = total thrust, T_R = roll thrust, T_P =pitch thrust, T_y = yaw thrust,

T_N =north, T_E =east, T_S =south and T_W =west

L =the length from the center of the structure to the thrust point,

K= the drag coefficient,

α = the thrust coefficient respectively.

Pilot – in – the – loop system

- Equations (1)-(4) can be represented as a transformation matrix, M, shown in Equation (5) that relates altitude thrust to motor thrust.

$$T_A = MT_M \rightarrow \underbrace{\begin{bmatrix} T_T \\ T_R \\ T_P \\ T_Y \end{bmatrix}}_{T_A} = \underbrace{\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & -1 & 1 \\ 1 & -1 & 0 & 0 \\ \kappa/\alpha & \kappa/\alpha & -\kappa/\alpha & -\kappa/\alpha \end{bmatrix}}_{M} \underbrace{\begin{bmatrix} T_N \\ T_S \\ T_E \\ T_W \end{bmatrix}}_{T_M} \qquad (5)$$

where, T_A *= altitude thrust ,* T_M *= Motor thrust*

Pilot – in – the – loop system

- The inverse of the transformation matrix, as given Equation (6), is more useful.

$$T_M = M^{-1}T_A \Rightarrow \begin{bmatrix} T_N \\ T_S \\ T_E \\ T_W \end{bmatrix} = \begin{bmatrix} 0.25 & 0 & \frac{1}{2l} & \frac{\alpha}{4\kappa} \\ 0.25 & 0 & \frac{-1}{2l} & \frac{\alpha}{4\kappa} \\ 0.25 & \frac{-1}{2l} & 0 & \frac{-\alpha}{4\kappa} \\ 0.25 & \frac{1}{2l} & 0 & \frac{-\alpha}{4\kappa} \end{bmatrix} \begin{bmatrix} T_T \\ T_R \\ T_P \\ T_Y \end{bmatrix} \quad (6)$$

Hardware Design

- Most structure is carbon fiber.
- Parts that experience force are made of aluminum.
- Connectors are made of ABS plastic.
- Overall weight = 2 Kg.

Fig 4. carbon fiber structure [5]

Hardware Design cont.

Motors

- Rimfire 35-36-1200kv brushless motors

Fig 5. Motor [6]

Fig 6. Motor controller [7]

Motor controllers

- Turnigy TR_B25A
- Motor controllers connect directly to the battery.

Pusher and Tractor rotors

- Ten inches in diameter.
- An aggressive pitch of 4.5 provides an excellent amount of thrust.
- Flexible and fragile nature reduces efficiency .

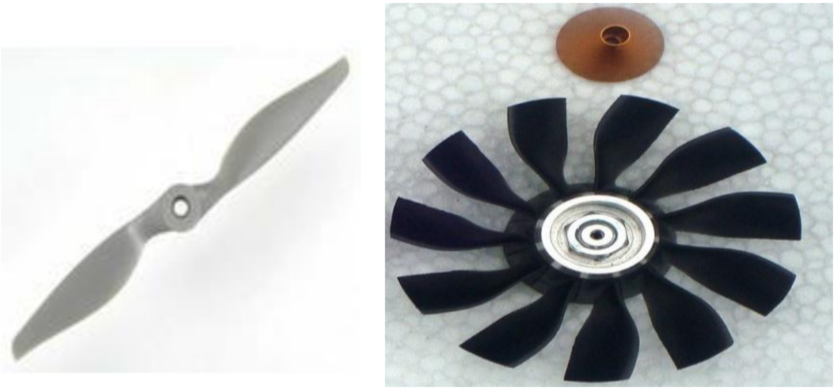


Fig 7. Pusher Rotor and Tractor Rotor [8]

Hardware Design cont.

Battery

- lithium-polymer batteries (4 cell, 6Ah)
- Battery damages internally if voltage falls below ~13V
- Temperature and voltage of the battery are continuously monitored.
- Fail-safe protocols are triggered in case of emergencies.

Fig 8. Battery [9]

Hardware Design cont.

Temperature sensors

- To read battery temperature.

Fig 9. Temperature Sensor [10]

Switching mode power supply (SMPS)

- To regulate the battery voltage down to the necessary operating voltage.

Fig 10. SMPS [11]

Hardware Design cont.

Analog-to-Digital Converter (ADC)

- Also can be used to monitor battery voltage.

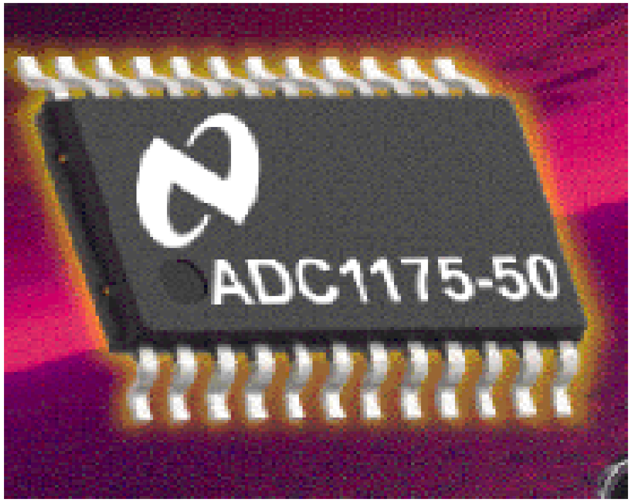


Fig 11. ADC [12]

Fig 12. AHRS [13]

An Altitude Heading Reference System (AHRS)

- Measure battery voltage
- 9 DOF Razor IMU

Hardware Design cont.

Sonar Sensor

- Parallax Ping Sensor.
- Measures altitude during take-off, landing and low-level flight.

Fig 13. Sonar Sensor [14]

GPS (Global Positioning System)

- Parallax PMB-248
- Measures latitude, longitude and altitude.
- For equipment recovery and data logging the signals are transmitted to monitoring station.

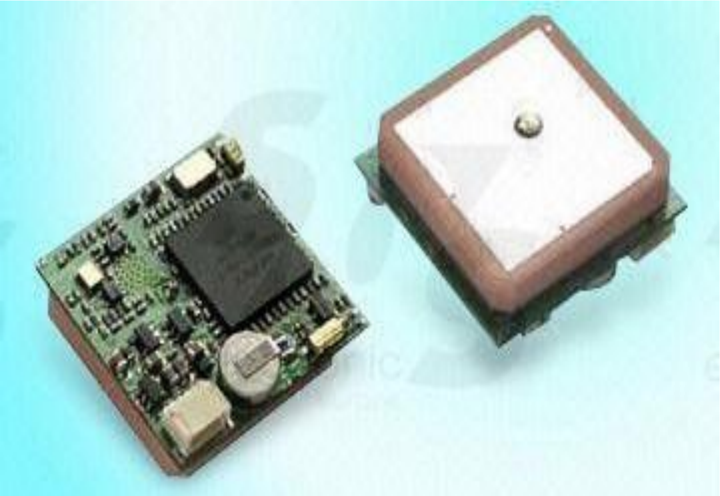


Fig 14. GPS [15]

Hardware Design cont.

Fig 15.Zigbee module [16]

Zigbee communication Module

- For communication between the Quadrotor and the monitoring station.
- reliable, short-range 2.4GHz communication channel

Micro controller

- Parallax propeller multi-core microcontroller can communicate and pass data amongst each other.

Fig 16. Micro controller [17]

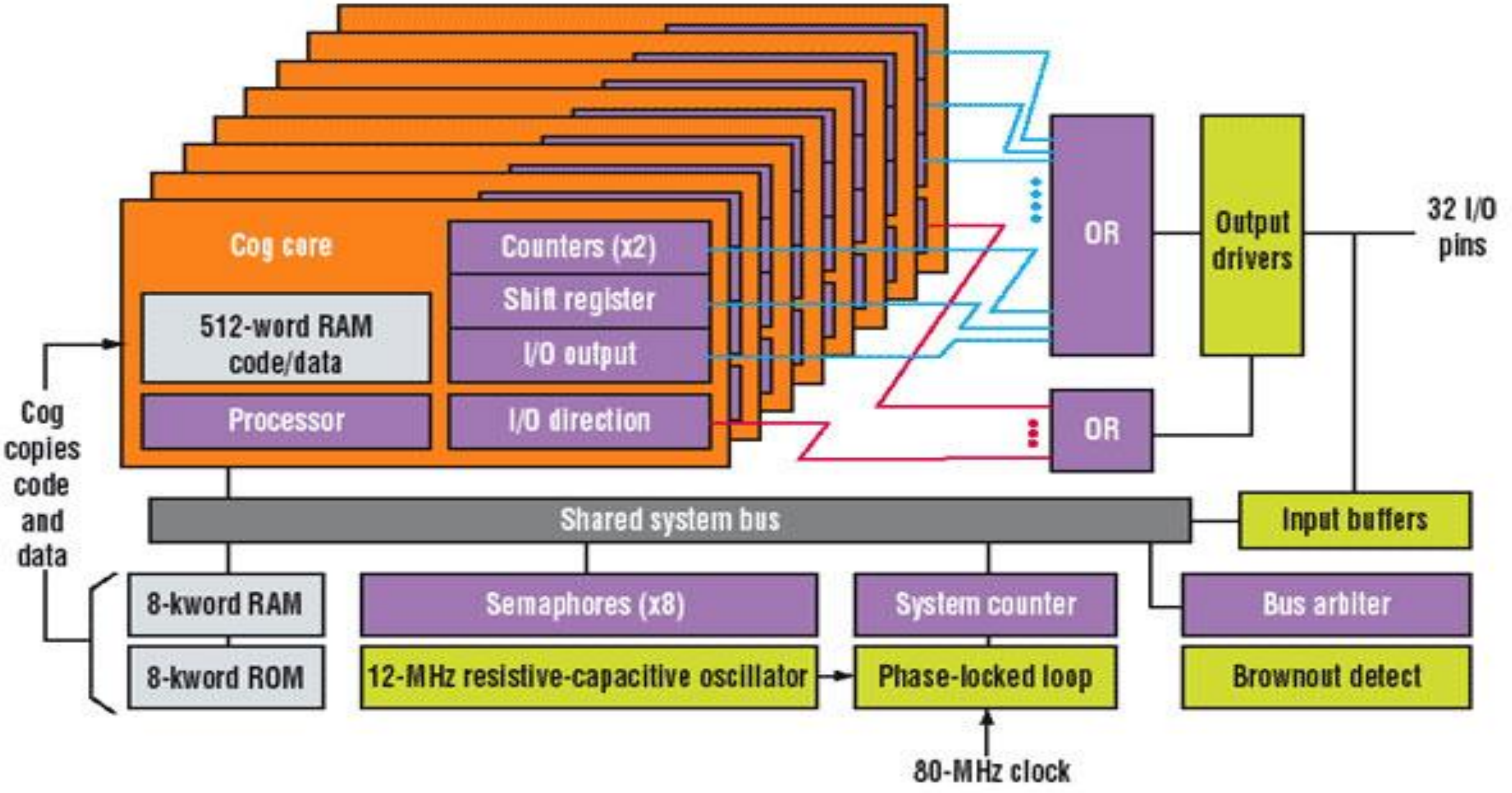
Multi-core Micro Controllers

- Parallax Propeller multi-core microcontrollers
- Architecture: 32-bits
- System Clock Speed: DC to 80 MHz

fig17 .MCU [18]

- Global RAM/ROM: 64 K bytes; 32 K RAM / 32 K ROM
- I/O Pins: 32 (simultaneously addressable by all eight cogs)

Multi-core Micro Controllers cont.



The Parallax Propeller powers up as many cog processing cores as necessary. Each core can utilize any combination of I/O pins. A cog gets one system bus time slot each per cycle, but it also can execute multiple instructions from local memory each cycle.

Fig 18. Internal Structure of micro controller [19]

Micro controller Software

- Programming language (high-level) : SPIN

```
VAR
  long Stk[3] ''declare an array of longs

PUB Main
  cognew(DispCnt, @Stk) ''Acvtivate cog 1 and run the DispCnt routine in it
  ''also pass the adress of the array we created, for use as a call stack
  Waitandstop ''Run Wait routine in this cog (cog 0)

PUB DispCnt
  dira~~ ''set all bits in port a direction register to 1 (output)
  repeat
    waitcnt(3_000_000 + cnt)
    outa := cnt ''move value current system counter to port a

PUB Waitandstop
  waitcnt(40_000_000 + cnt) ''wait until counter = current value + 40,000,000 (wait 40mil clocks)
  cogstop(1) ''stop cog 1
  cogstop(0) ''stop cog 0
```

Fig 19 . Software micro controller [20]

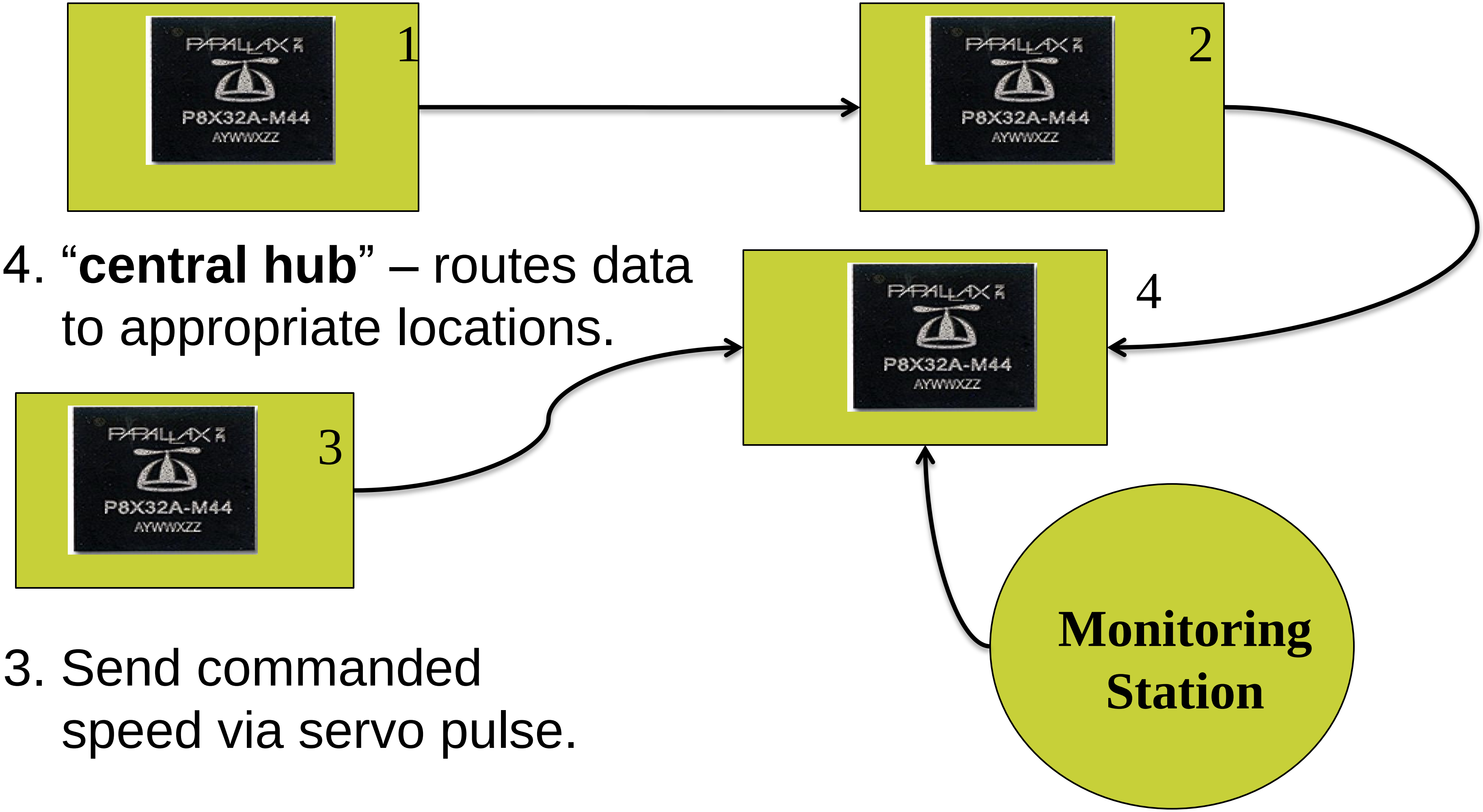
Multi-core Micro controller

1. compute and pass data from AHRS.

2. Receive and interpret GPS information.

4. "**central hub**" – routes data to appropriate locations.

3. Send commanded speed via servo pulse.



Linearization Techniques

- Control loops: Roll, Yaw, Pitch and Altitude.
- Pounds Equation: [6]

$$\dot{T}_i = -AT_i + Bu_i$$

$$\text{where } i = N, S, E, \text{and } W,$$

$$A = \frac{2}{\tau} + \frac{3\kappa}{2\sqrt{\alpha}}\sqrt{T_0}, \quad \text{and } B = \frac{2\sqrt{\alpha}\kappa}{\tau}\sqrt{T_0}$$

satisfied only adaptive PID controller and for first order systems

Linearization Equations

Generic system model is given as :

$$\frac{y(k)}{u(k)} = \frac{b_1 q^{-1} + b_2 q^{-2}}{1 + a_1 q^{-1} + a_2 q^{-2}} = \frac{B(q^{-1})}{A(q^{-1})}$$

- Solving for gain equations:

$$K_i = \frac{-(g_0 + g_1 + g_2)}{S_T}, \quad K_p = \frac{g_1 + 2g_2}{1 + r_1},$$

$$K_d = S_T \left[\frac{r_1 g_1 - (1 - r_1) g_2}{1 + r_1} \right]$$

Implementing Linearization Model

- Successfully implemented on embedded environment.
- Adaptive algorithm and linearized gave successful results on MATLAB.
- Adaptive PID control did not produce expected results for second-order systems for pitch and roll channels.
- Gains from digital implementation of standard PID control was suitable for Quad rotor flight control.

Problems Encountered

- Motor controllers were directly below the rotors leading to reduction of lift.
- Battery life was another major concern.
- The use of more motors made the craft more maneuverable but also requires more power.
- Flight time varies with the motor specifications.

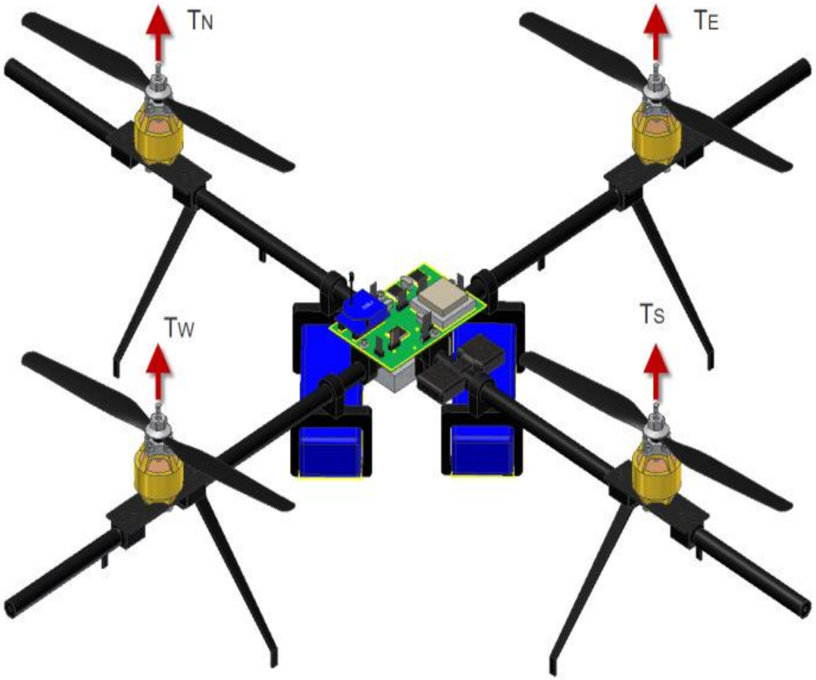


Fig 20 Quad rotor [21]

Conclusions

- Hardware Design was successfully implemented.

- Adaptive PID controller based on a second-order model is not sufficient for the control of a quad rotor on the pitch or roll channels.

- Adequacy of the standard PID control was validated on the pitch, roll and altitude channels.

- Further work include use of non-adaptive PID in adaptive PID to obtain starting point and limit gains around known tuning parameters.

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Pictures

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